

SCATHA/SC3 DATA PROCESSING AND CROSS- CALIBRATION WITH LANL-GEO/CPA FOR AE9 DEVELOPMENT

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Technical Report

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14. ABSTRACT This report summarizes processing and cross calibration of electron data from the Spacecraft Charging AT High Altitudes (SCATHA) SC3 spectrometer for use in the AE9 radiation belt model. The processed and cleaned data were cross calibrated with four LANL GEO satellites. Identification of conjunctions and results for cross calibration factors and residual errors are provided. The data used in this report are from 1979 to 1989.					
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Table of Contents

1. INTRODUCTION	1
2. BACKGROUND	1
3. METHODS, ASSUMPTIONS, AND PROCEDURES	1
3.1. Data Processing.....	1
3.2. Data Cleaning.....	2
3.3. Data Used in Cross-Calibration	3
3.4. Conjunctions Used	4
4. RESULTS AND DISCUSSION.....	4
5. CONCLUSIONS.....	7
REFERENCES	8
APPENDIX: ADDITIONAL FIGURES.....	9

List of Figures

1. Data cleaning plots.....	3
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List of Tables

1. Information for the 24 energy channels of SCATHA/SC3.....	2
2. Center energies of energy channels (MeV)	3
3. Conjunction criteria	4
4. Conjunction events.....	4
5. Cross calibration results for SCATHA and LANL 1981-025 ($6.59 \leq L_m \leq 7.20$).....	5
6. Cross calibration results for SCATHA and LANL 1982-019 ($6.74 \leq L_m \leq 7.32$).....	5
7. Cross calibration results for SCATHA and LANL 1984-037 ($6.60 \leq L_m \leq 7.11$).....	6
8. Cross calibration results for SCATHA and LANL 1984-129 ($6.54 \leq L_m \leq 6.99$).....	6

1. INTRODUCTION

This report summarizes processing and cross calibration of electron data from the Spacecraft Charging AT High Altitudes (SCATHA) SC3 spectrometer for use in the AE9 radiation belt model. The processed and cleaned data were cross calibrated with four GEO satellites (1981-025, 1982-019, 1984-037, and 1984-129). Identification of conjunctions and results for cross calibration factors and residual errors are provided. The data used in this report are from 1979 to 1989.

2. BACKGROUND

AE9/AP9/SPM is a new model of the trapped radiation and plasma near-Earth environment for use in satellite design. In the case of the energetic electron component, AE9, over 16 data sets were used to develop the model. These data sets were processed, cleaned, and cross-calibrated to provide a consistent basis for merging into the final flux maps. This document describes the process as applied to the SCATHA/SC3 data set.

As a joint Air Force/NASA satellite mission, the Spacecraft Charging AT High Altitudes (SCATHA) was launched on 30 January 1979 as into a highly elliptical transfer orbit having an apogee of 43,183km, a perigee of 176 km, and an inclination of 27.3°. On 2 February 1979, SCATHA was inserted into its final, near-synchronous Earth orbit at 7.9° inclination with apogee at 43,192 km (~7.8 R_E), perigee at 27,517 km (~5.3 R_E), and period of 23.597 hours [1, 2]. This mission lasted about 11 years.

The SC3 spectrometer on board SCATHA measured the fluxes and pitch-angle (PA) distributions of energetic electrons in the energy range 47 keV to 5 MeV. Information on the 24 energy channels is listed in Table 1 [1]. The center energy is in the unit of keV, while the geometric factor term (G_FΔE)⁻¹ is in units of cm⁻² sr⁻¹ keV⁻¹.

3. METHODS, ASSUMPTIONS, AND PROCEDURES

3.1 Data Processing

The SCATHA data were recovered in late 1990s by the Aerospace Corporation and a different table of geometric factor parameters was provided by Fennell et al. [3]. However, the geometric factors by Fennell et al. [3] are only available for 12 low energy channels; hence, we have chosen to adopt parameters provided by Reagan et al. [1] to convert count rates to differential energy fluxes (j) with an equation

$$j = \text{counts} / (\Delta t G_F \Delta E) \tag{1}$$

for both low and high energy channels.

Table 1: Information for the 24 energy channels of SCATHA/SC3.

Low Energy Mode				High Energy Mode			
Center E (keV)	Energy range (keV)	ΔE (keV)	$(G_F \Delta E)^{-1}$ (cm ⁻² sr ⁻¹ keV ⁻¹)	Center E (keV)	Energy range (keV)	ΔE (keV)	$(G_F \Delta E)^{-1}$ (cm ⁻² sr ⁻¹ keV ⁻¹)
56.7	47-66	19	19.9	448.5	260-630	370	1.74
76.7	66-87	21	18.7	830	630-1030	400	1.05
97.5	87-108	21	18.3	1222.5	1030-1420	390	1.08
118.5	108-129	21	18.3	1616.5	1420-1810	390	1.14
139.5	129-150	21	18.3	2011	1810-2210	400	1.22
160.5	150-171	21	18.3	2405.5	2210-2600	390	1.26
181.5	171-192	21	18.6	2800	2600-3000	400	1.38
203	192-214	22	17.9	3195	3000-3390	390	1.48
224.5	214-235	21	19.5	3590	3390-3790	400	1.80
245.5	235-256	21	22.2	3904	3790-4180	390	2.14
267	256-278	22	25.5	4378	4180-4580	400	3.25
288.5	278-299	21	32.9	4772.5	4580-4970	390	3.68

The electron count rate data used in AE9/AP9 were extracted from high-resolution Common Data Format (CDF) files provided by the Aerospace Corporation. The original time resolution of the SC3 data is 0.496 sec. In order to reduce the SCATHA/SC3 data set to a manageable size, measured count rates have been averaged over 5-min intervals in 9 local pitch angle bins from 0° to 90°. Each pitch angle bin has a resolution of 10°.

The SCATHA satellite ephemeris information contained in the associated “summary CDF” files was determined to be very poor quality and contained many unphysical position shifts. A database of SCATHA satellite orbit two-line element (TLE) sets was obtained from the Aerospace Corporation. The ‘Lokangle’ propagator was used to generate a replacement set of ephemeris information from a filtered version of this TLE database; many TLE entries that were deemed suspicious, or those that caused unphysical position shifts, were removed.

3.2 Data Cleaning

Three types of data cleaning processes were performed (1) to correlate count rates from neighboring energy channels (Fig. 1a-b); (2) to plot count rates for one energy channel against itself at a 5-min time lag (Fig. 1c); and (3) to use the median values to filter out spurious high count rates. Examples of cleaning methods are shown in Figure 1. Suspicious points outside a selected diagonal range marked by two black lines (Fig. 1a and 1c) were flagged and were not included in the product. Energy channel 13 did not function properly after the first two years of operation as seen in Figure 1b, hence, data from this energy channel (highlighted red in Table 1) has been excluded in the product.

Finally, electron fluxes of 23 energy channels with time and pitch angle resolution of 5 min and 10° [i.e., $j(nE=23, nPA=9, \Delta t=5 \text{ min})$] along with corresponding L_m , K , ϕ , and HMIN were generated to be used in the AE9/AP9 product.

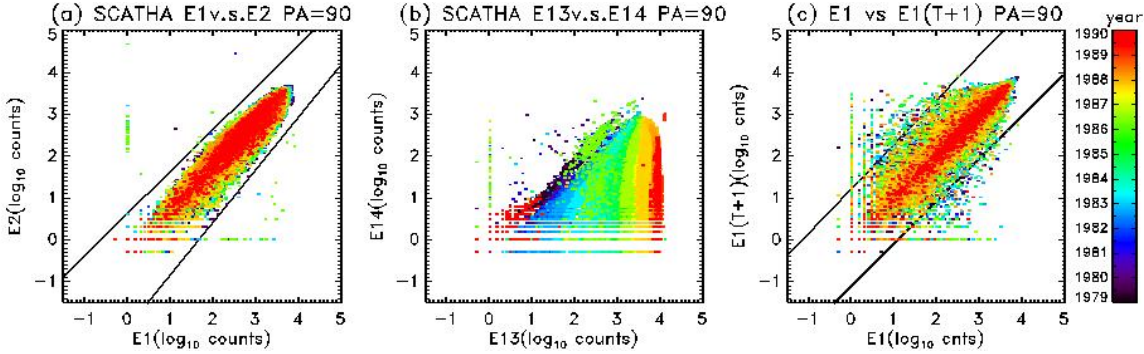


Figure 1. Data cleaning plots:

(a) Correlation between two adjacent energy channels, 1 and 2, for pitch angles 80° - 90° . Data points outside the two diagonal solid black lines were excluded in our statistical study. The color bar on the right of each panel indicates the year of mission. (b) Correlation between energy channels 13 and 14. This panel and other information (not shown) indicate that the energy channel 13 does not provide accurate count rate measurements for the majority period of the mission. (c) A plot of energy channel 1 against itself at a 5-min time lag. Again, data points above the upper black line and below the lower line were excluded in our statistics.

3.3 Data Used in Cross-Calibration

For use in AE9, SCATHA data were cross-calibrated with LANL GEO/CPA data. The LANL GEO data are spin-averaged omni-directional CPA data, at 1 min intervals, from satellites 1981-025, 1982-019, 1984-037, and 1984-129. The CPA instrument has 11 electron energy channels in the range of 0.04-1.6 MeV. The SC3 instrument on SCATHA has 24 electron energy channels from 0.05-5 MeV. In this cross calibration, SCATHA data are averaged over pitch angles with 5 min time resolution. The energy channels used here are highlighted in grey in Table 2. The log fluxes of LANL channels have been linearly interpolated based on the SCATHA/SC3 log center energies.

Table 2: Center energies of energy channels (MeV)

Channel	1	2	3	4	5	6	7	8	9	10	11	12
SCATHA	0.057	0.077	0.098	0.119	0.140	0.161	0.182	0.203	0.225	0.246	0.267	0.289
LANL	0.037	0.054	0.079	0.115	0.167	0.245	0.346	0.488	0.735	1.123	1.673	-
Channel	13	14	15	16	17	18	19	20	21	22	23	24
SCATHA	0.449	0.830	1.223	1.617	2.011	2.406	2.800	3.195	3.590	3.904	4.378	4.773

3.4 Conjunctions Used

The conjunction criteria, shown in Table 3, are based on those of Friedel et al. [4] but modified for the case of SCATHA-GEO conjunctions. It should be noted that some criteria used in other AE9 cross-calibrations are not used here. No restriction of $L_m < 6.5$ is used because all conjunction events were found when L_m ($PA=90^\circ$) is greater than 6.5. No restriction on K_p is used because the conjunction events dramatically decrease with a restriction $K_p < 2$ for the last 48 hrs.

The number of conjunction points for the SCATHA-GEO pairs are listed on Table 4. Each of SCATHA points has been reproduced to match the GEO resolution in the cross calibration.

Table 3: Conjunction criteria

Quantity	Criterion
ΔL_m	< 0.1
$\Delta (B/B_0)$	< 0.1
ΔUT (hr)	< 3
MLT	4-8 or 16-20 LT

Table 4: Conjunction events

Satellite Pair	SCATHA 1981-025	SCATHA 1982-019	SCATHA 1984-037	SCATHA 1984-129
# SCATHA points (5 min resolution)	611	1066	472	517
# GEO points (1 min resolution)	3434	6041	2479	2940

4. RESULTS AND DISCUSSION

Cross-calibration statistics were obtained for SC3 channels 1-17, representing the range of overlap with CPA channel energies. Tables 5-8 present results for comparisons of SCATHA to each of four GEO satellites, including number of conjunction points N , mean and median ratios, correlation coefficient, and root-mean-squared-error (RMSE).

It should be noted that Energy Channel 13 is bad after 1981, hence, not many data points for statistics (see Table 4, highlighted grey, and the top panel of Page 4). We recommend ignoring Channel 13 entirely.

Table 5. Cross calibration results for SCATHA and LANL 1981-025 ($6.59 \leq L_m \leq 7.20$)

Channel	E (MeV)	N	Mean (A)	Median (R)	Corr. Coef.	RMSE(dlnj)
1	0.0567	3413	0.4495	0.3067	0.308	0.8348
2	0.0767	3413	0.5700	0.4133	0.296	0.7989
3	0.0975	3407	0.6634	0.5102	0.351	0.7531
4	0.1185	3406	0.7558	0.5387	0.378	0.7681
5	0.1395	3406	0.8333	0.5874	0.422	0.7293
6	0.1605	3406	0.8550	0.5930	0.444	0.7216
7	0.1815	3406	0.9040	0.6430	0.446	0.7191
8	0.2030	3406	0.8462	0.6192	0.446	0.7163
9	0.2245	3406	0.8888	0.6651	0.452	0.7157
10	0.2455	3427	0.8953	0.6768	0.480	0.7194
11	0.2670	3424	0.7971	0.5926	0.494	0.7239
12	0.2885	3415	0.7805	0.5768	0.496	0.7202
13	0.4485	172	1.6941	1.0449	0.912	0.7976
14	0.8300	3272	0.7907	0.6875	0.755	0.7219
15	1.2225	3003	0.8246	0.6669	0.820	0.6347
16	1.6165	2226	0.8275	0.5795	0.757	0.6997
17	2.0110	1397	0.5027	0.4060	0.605	0.6389

Table 6. Cross calibration results for SCATHA and LANL 1982-019 ($6.74 \leq L_m \leq 7.32$)

Channel	E (MeV)	N	Mean (A)	Median (R)	Corr. Coef.	RMSE(dlnj)
1	0.0567	5919	1.9045	0.4066	0.338	1.0629
2	0.0767	5911	1.4532	0.4430	0.399	0.9959
3	0.0975	5955	1.3187	0.5478	0.469	0.9398
4	0.1185	6013	4.0138	0.6306	0.396	1.1181
5	0.1395	6009	4.4458	0.7013	0.442	1.1050
6	0.1605	5950	4.7089	0.7132	0.430	1.0990
7	0.1815	5945	4.7711	0.8463	0.459	1.0749
8	0.2030	5927	4.1268	0.8817	0.490	1.0448
9	0.2245	5903	4.1348	1.0323	0.499	1.0294
10	0.2455	5886	4.0536	1.1405	0.509	1.0176
11	0.2670	5799	3.5214	1.0649	0.526	0.9751
12	0.2885	5695	3.4550	1.0722	0.544	0.9513
14	0.8300	5568	2.5265	1.3409	0.726	0.9693
15	1.2225	3974	3.9607	1.6013	0.702	1.0186
16	1.6165	2403	5.2497	2.0774	0.637	1.1173
17	2.0110	1228	8.5467	2.2600	0.523	1.1217

Table 7. Cross calibration results for SCATHA and LANL 1984-037 ($6.60 \leq L_m \leq 7.11$)

Channel	E (MeV)	N	Mean (A)	Median (R)	Corr. Coef.	RMSE(dlnj)
1	0.0567	2345	0.5621	0.3169	0.122	1.1255
2	0.0767	2339	0.5273	0.3592	0.195	1.0172
3	0.0975	2333	0.6403	0.5136	0.280	0.9840
4	0.1185	2333	0.7664	0.5678	0.311	1.0095
5	0.1395	2327	0.9547	0.6019	0.357	1.0116
6	0.1605	2295	1.1523	0.6321	0.452	0.9338
7	0.1815	2289	1.2410	0.6887	0.490	0.9210
8	0.2030	2271	1.1222	0.6606	0.462	0.9151
9	0.2245	2234	1.1576	0.6972	0.487	0.8430
10	0.2455	2234	1.1377	0.6912	0.492	0.8512
11	0.2670	2228	1.1195	0.6570	0.485	0.8781
12	0.2885	2223	1.2054	0.6855	0.486	0.9059
14	0.8300	2197	3.8774	0.9329	0.674	1.2923
15	1.2225	1571	3.7034	1.2076	0.797	1.0415
16	1.6165	1093	7.6871	1.2187	0.610	1.3271
17	2.0110	917	11.8299	1.0811	0.521	1.5262

Table 8. Cross calibration results for SCATHA and LANL 1984-129 ($6.54 \leq L_m \leq 6.99$)

Channel	E (MeV)	N	Mean (A)	Median (R)	Corr. Coef.	RMSE(dlnj)
1	0.0567	2940	0.3476	0.2364	0.250	0.9520
2	0.0767	2940	0.3593	0.2587	0.390	0.7829
3	0.0975	2940	0.4587	0.3690	0.497	0.6858
4	0.1185	2940	0.5349	0.4542	0.558	0.6599
5	0.1395	2940	0.5444	0.4891	0.603	0.6356
6	0.1605	2940	0.5258	0.4712	0.627	0.6252
7	0.1815	2940	0.5987	0.5569	0.679	0.6025
8	0.2030	2940	0.6433	0.6116	0.729	0.5742
9	0.2245	2940	0.7745	0.7563	0.763	0.5662
10	0.2455	2940	0.8925	0.8749	0.777	0.5687
11	0.2670	2940	0.8258	0.7930	0.789	0.5735
12	0.2885	2940	0.8684	0.7917	0.785	0.5889
14	0.8300	2781	1.4866	1.0224	0.816	0.6787
15	1.2225	2568	1.6599	1.1826	0.790	0.6933
16	1.6165	2092	1.5721	1.0873	0.490	0.6947
17	2.0110	1914	1.3159	0.9226	0.352	0.6967

5. CONCLUSIONS

Electron data from the SC3 instrument on the SCATHA satellite were processed and cleaned for use in AE9. Cross-calibration was performed against CPA data from four LANL-GEO satellites: 1981-025, 1982-019, 1984-037, and 1984-129. This provided calibration statistics for channels 1-12 and 14-17 of SC3, the range of overlap with CPA channel energies. As the SC3 channel 13 data is bad after 1981, insufficient statistics were available for cross-calibration and we recommend not using this channel.

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APPENDIX: ADDITIONAL FIGURES

The following additional figures show calibration results for each SCATHA-GEO satellite pairing and scatter plots of each channel for each pairing. Figures A1-A4 show ratios of SCATHA fluxes to GEO fluxes as a function of energy, including: mean (black line with solid circles); median (red line with solid circles); 32nd & 68th percentiles (blue lines); and 5th and 95th percentiles (light blue lines). The remaining figures each show SCATHA fluxes vs. GEO fluxes for a single pairing and single channel:

- Figures A5-A21: Cross calibration between SCATHA and 1981-025
- Figures A22-A37: Cross calibration between SCATHA and 1982-019
- Figures A38-A53: Cross calibration between SCATHA and 1984-037
- Figures A52-A69: Cross calibration between SCATHA and 1984-129

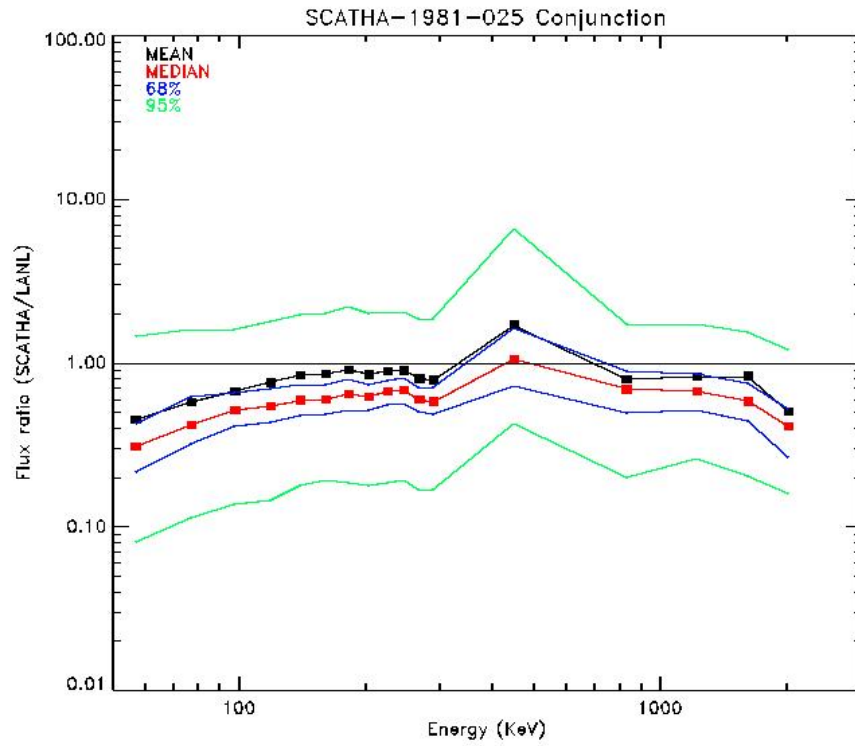


Figure A1: Cross-calibration results, SCATHA to 1981-025

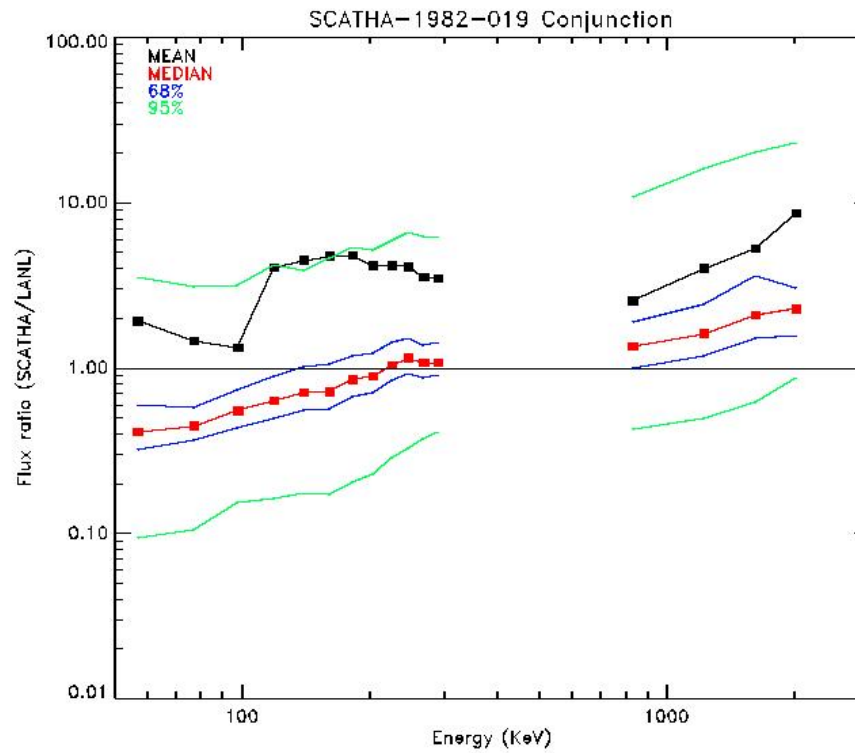


Figure A2: Cross-calibration results, SCATHA to 1982-019

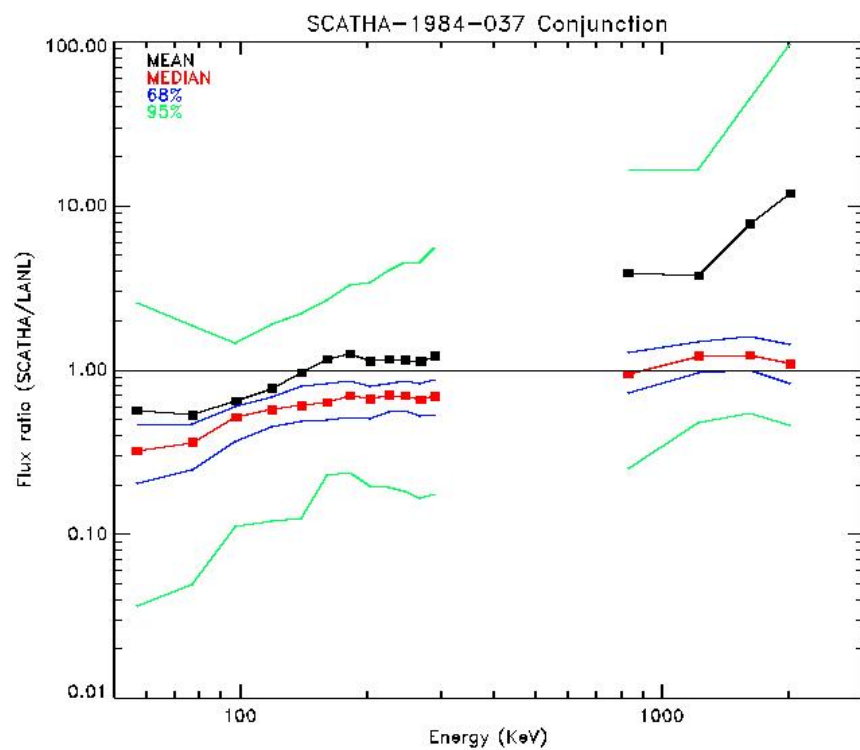


Figure A3: Cross-calibration results, SCATHA to 1984-037

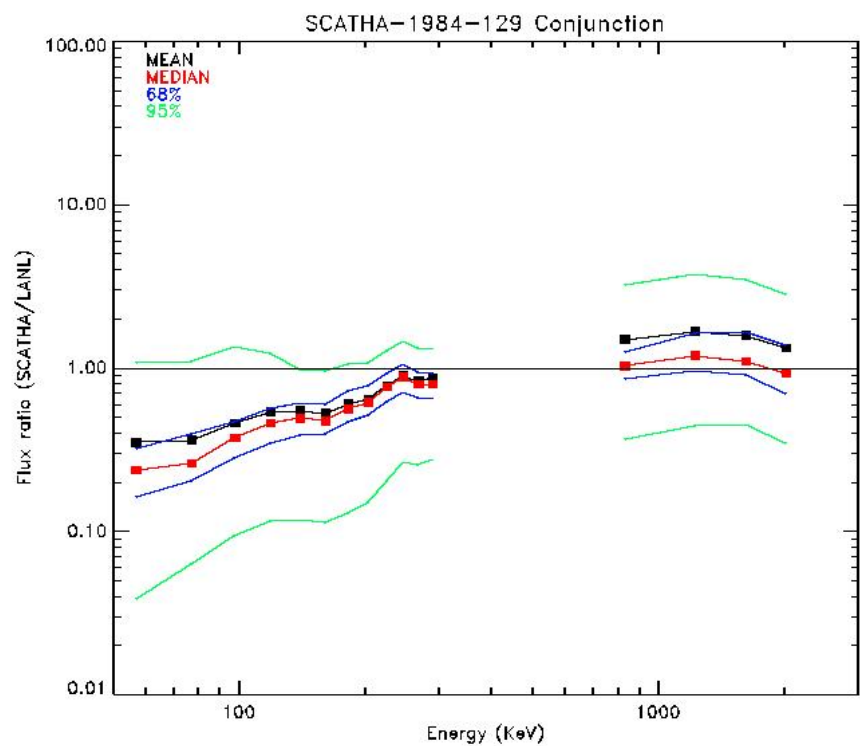


Figure A4: Cross-calibration results, SCATHA to 1984-129

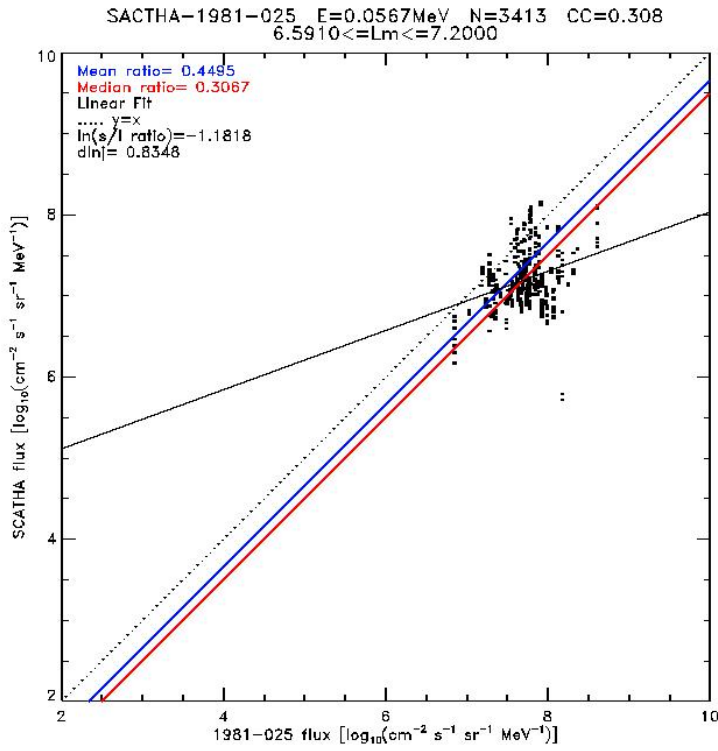


Figure A5: Cross-calibration results, SCATHA vs. 1981-025, E=56.7 keV

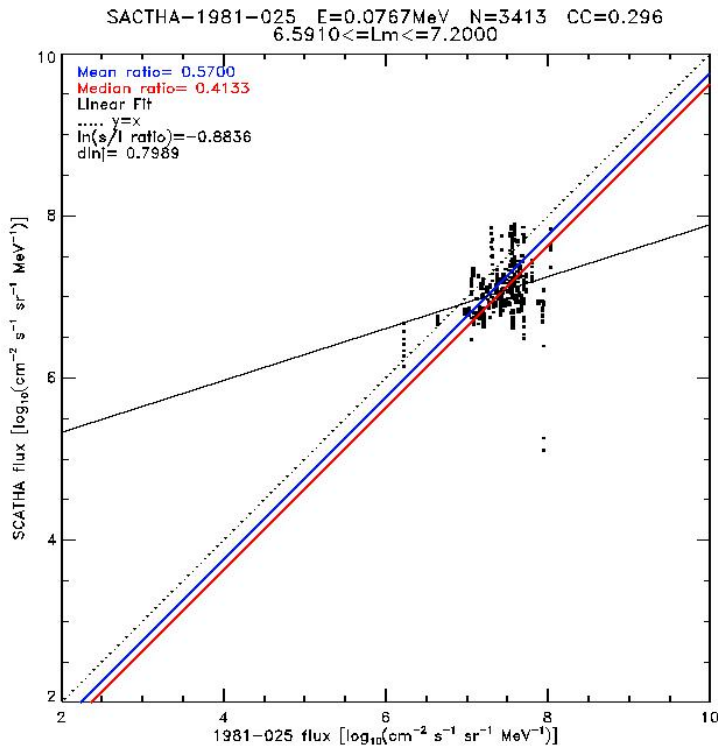


Figure A6: Cross-calibration results, SCATHA vs. 1981-025, E=76.7 keV

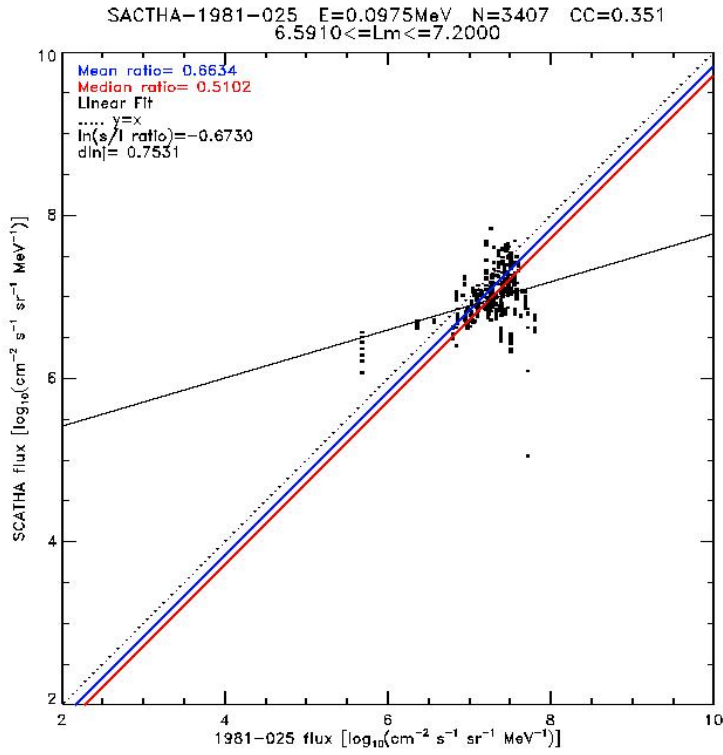


Figure A7: Cross-calibration results, SCATHA vs. 1981-025, E=97.5 keV

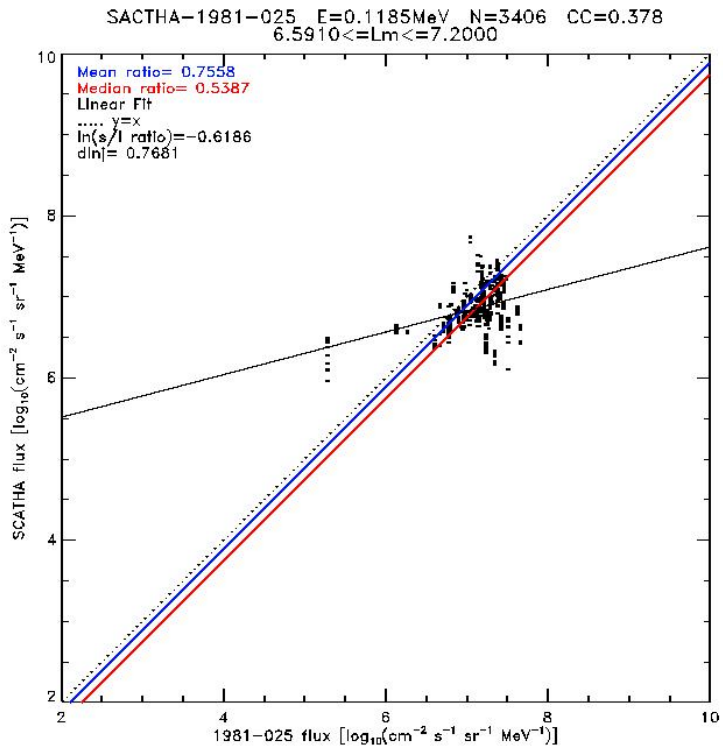


Figure A8: Cross-calibration results, SCATHA vs. 1981-025, E=118.5 keV

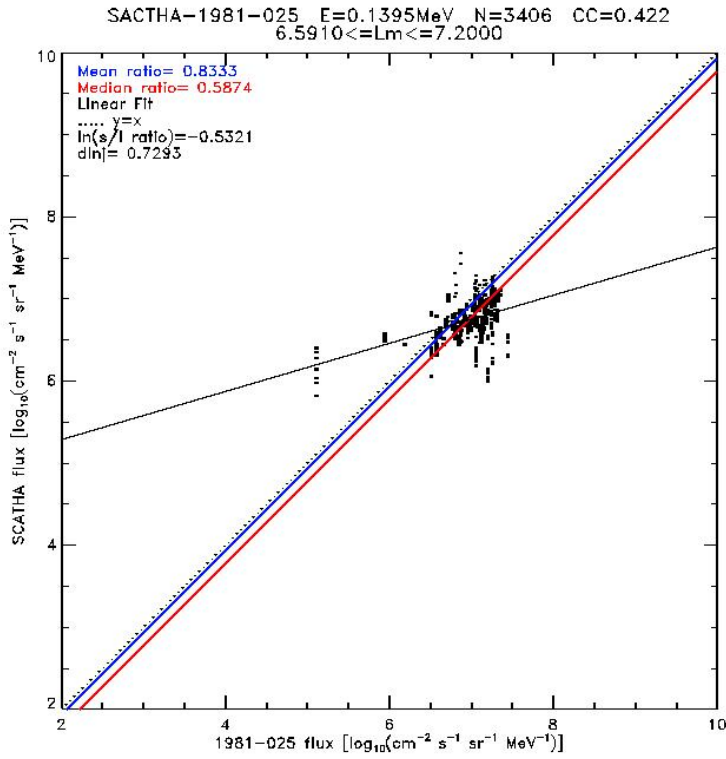


Figure A9: Cross-calibration results, SCATHA vs. 1981-025, E=139.5 keV

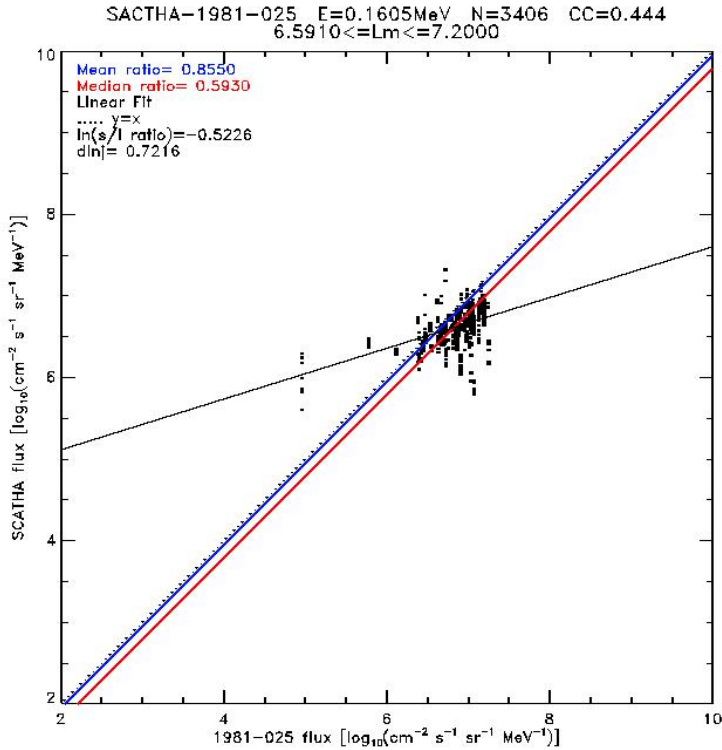


Figure A10: Cross-calibration results, SCATHA vs. 1981-025, E=160.5 keV

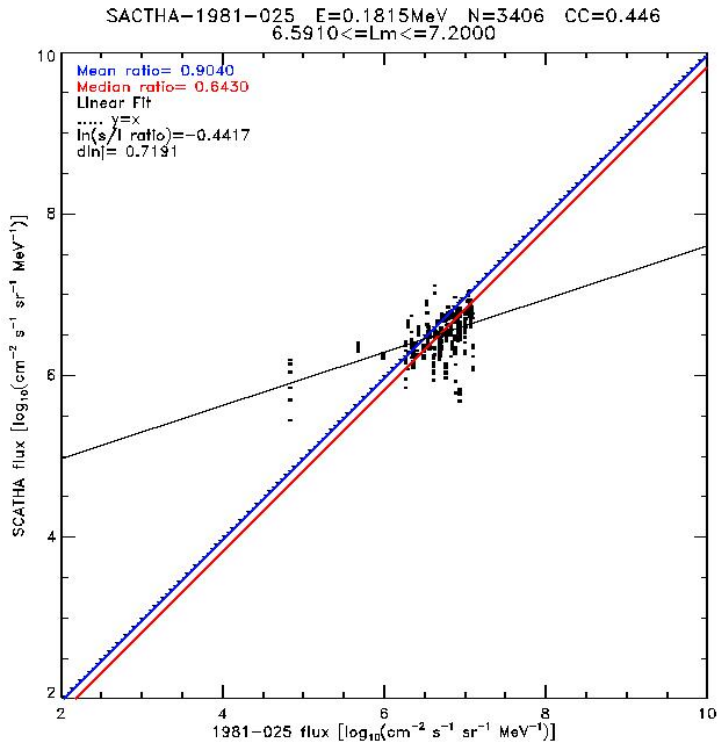


Figure A11: Cross-calibration results, SCATHA vs. 1981-025, E=181.5 keV

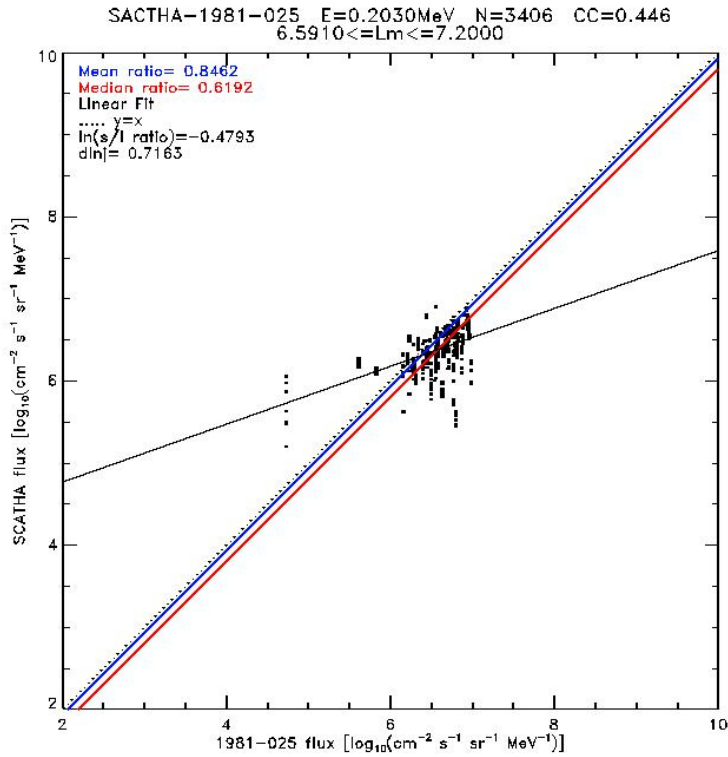


Figure A12: Cross-calibration results, SCATHA vs. 1981-025, E=203 keV

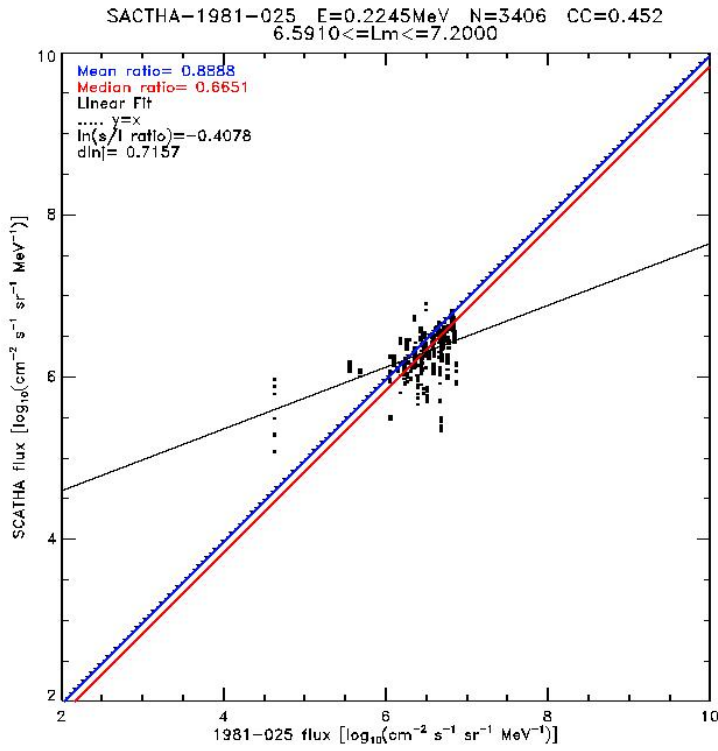


Figure A13: Cross-calibration results, SCATHA vs. 1981-025, E=224.5 keV

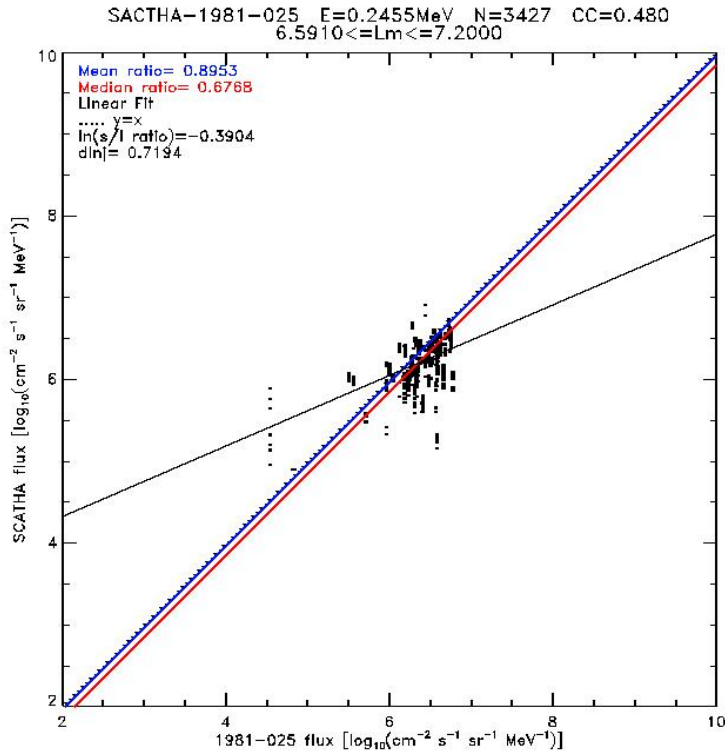


Figure A14: Cross-calibration results, SCATHA vs. 1981-025, E=245.5 keV

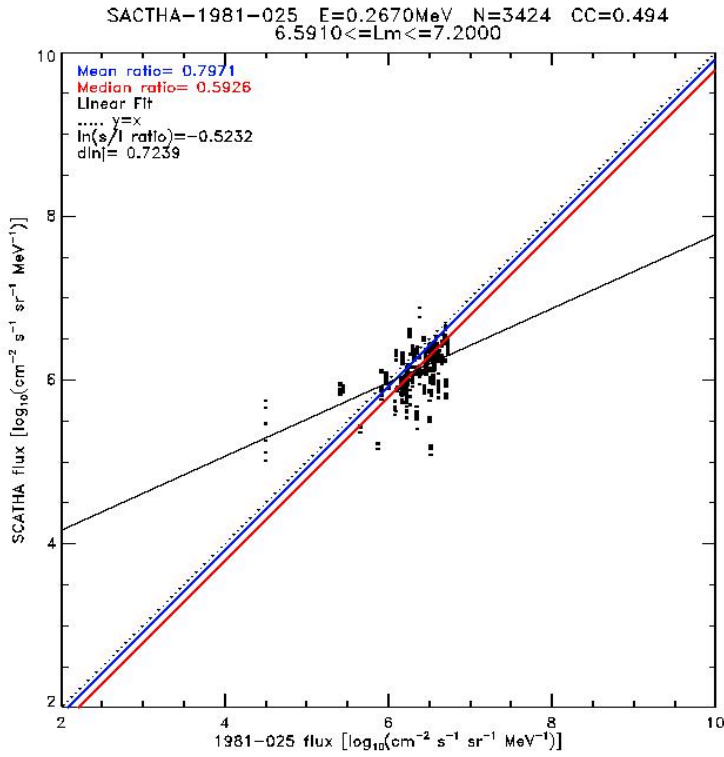


Figure A15: Cross-calibration results, SCATHA vs. 1981-025, E=267 keV

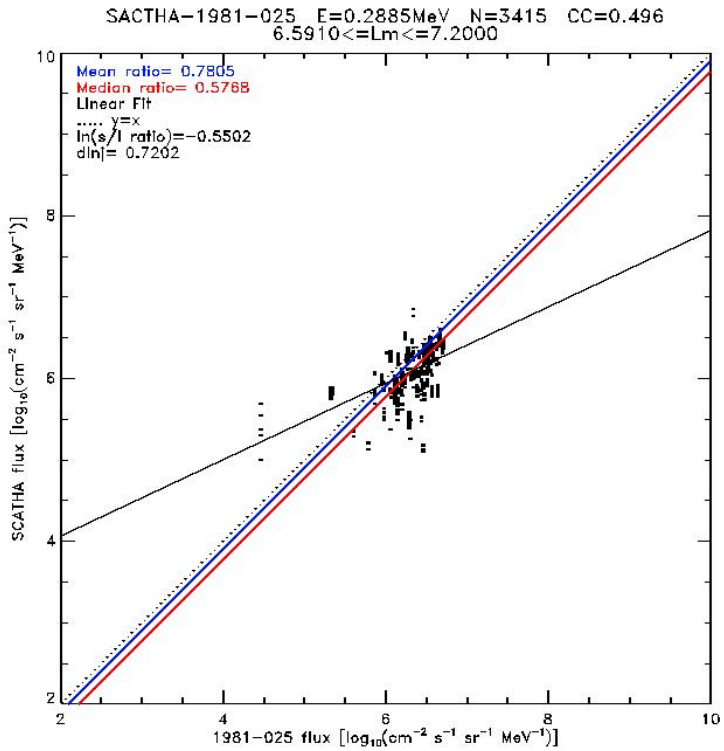


Figure A16: Cross-calibration results, SCATHA vs. 1981-025, E=288.5 keV

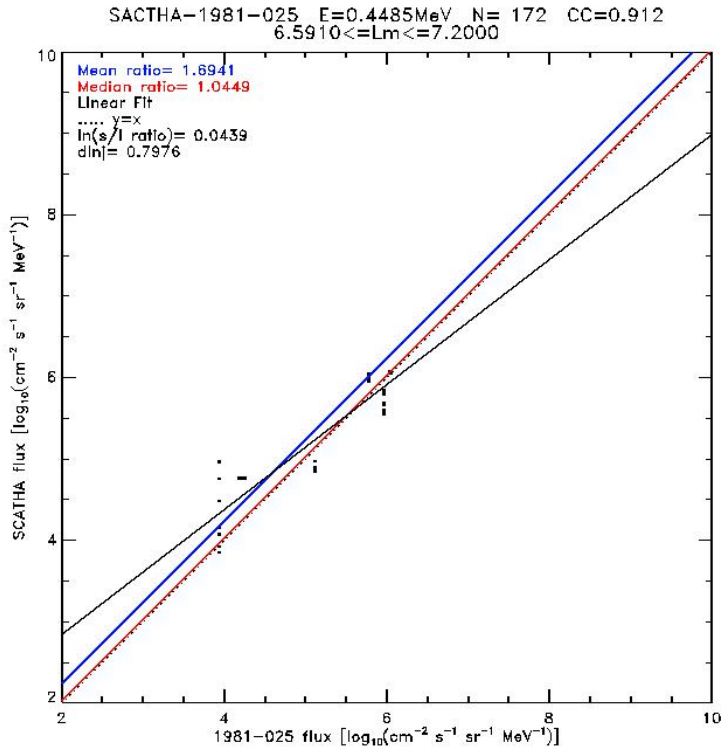


Figure A17: Cross-calibration results, SCATHA vs. 1981-025, E=448.5 keV

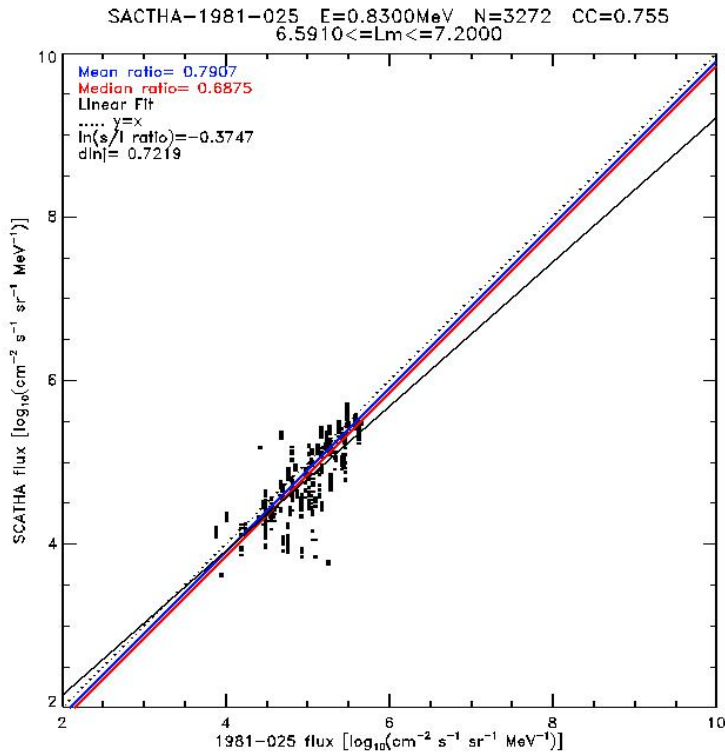


Figure A18: Cross-calibration results, SCATHA vs. 1981-025, E=830 keV

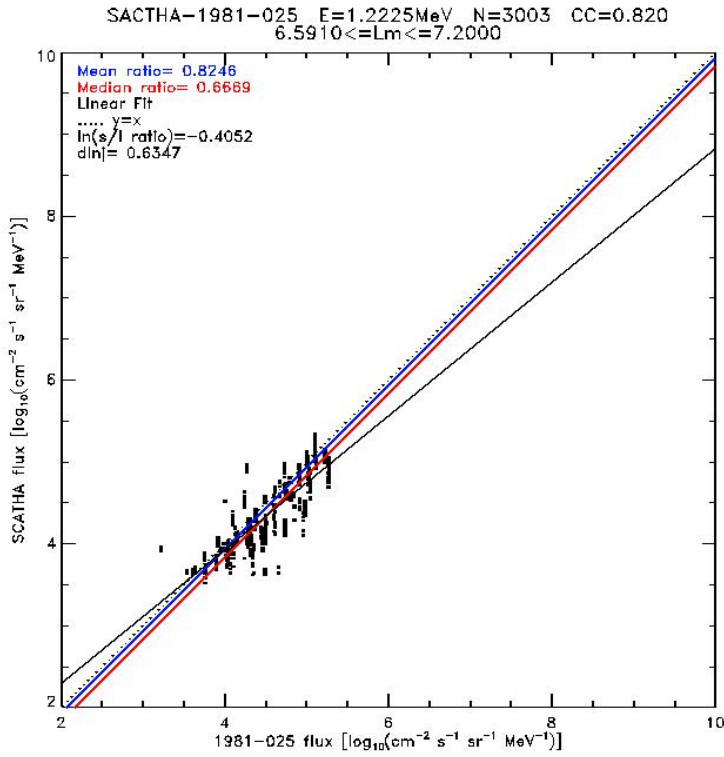


Figure A19: Cross-calibration results, SCATHA vs. 1981-025, E=1222.5 keV

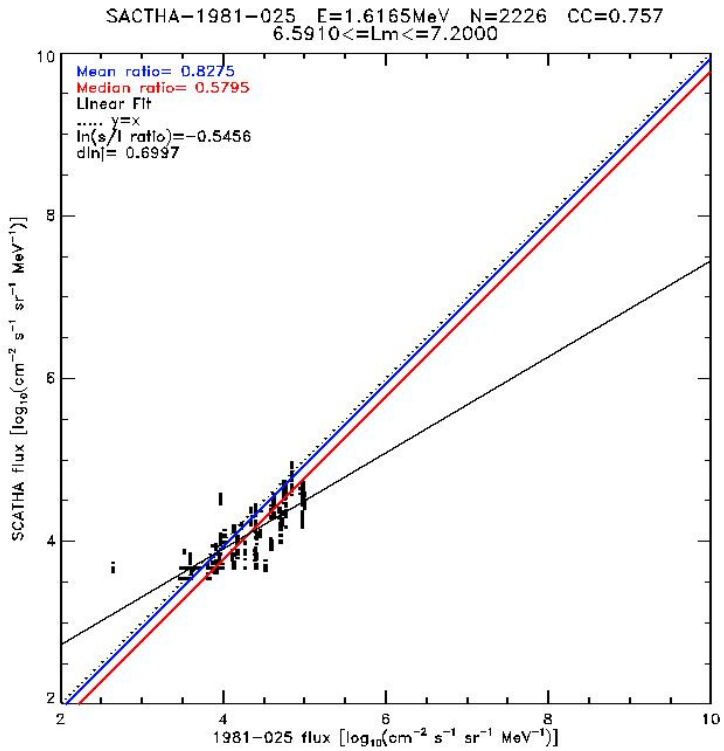


Figure A20: Cross-calibration results, SCATHA vs. 1981-025, E=1616.5 keV

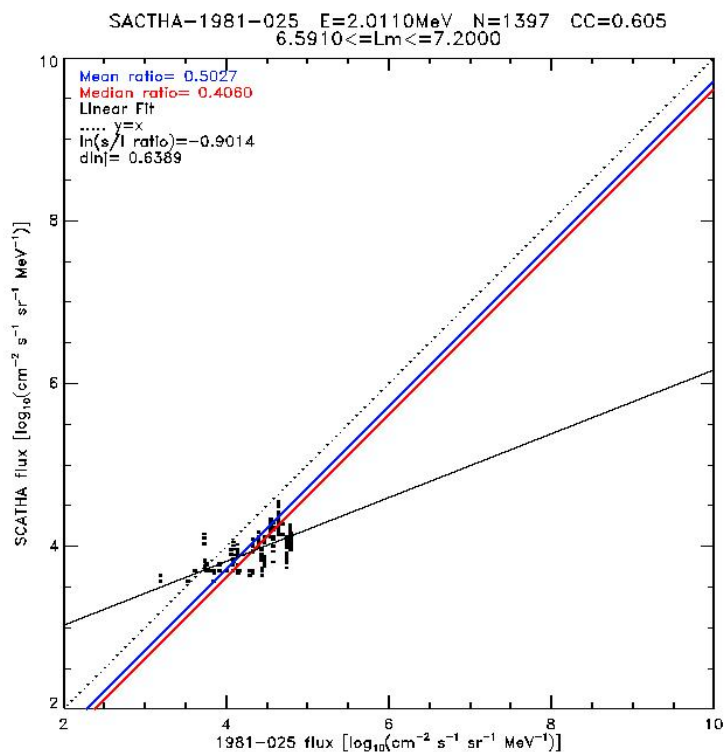


Figure A21: Cross-calibration results, SCATHA vs. 1981-025, E=2011 keV

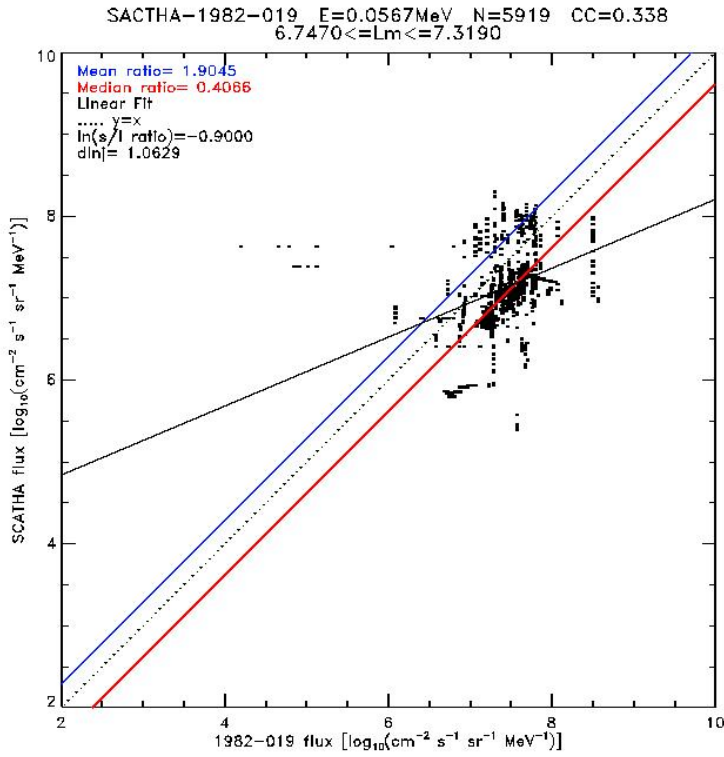


Figure A22: Cross-calibration results, SCATHA vs. 1982-019, E=56.7 keV

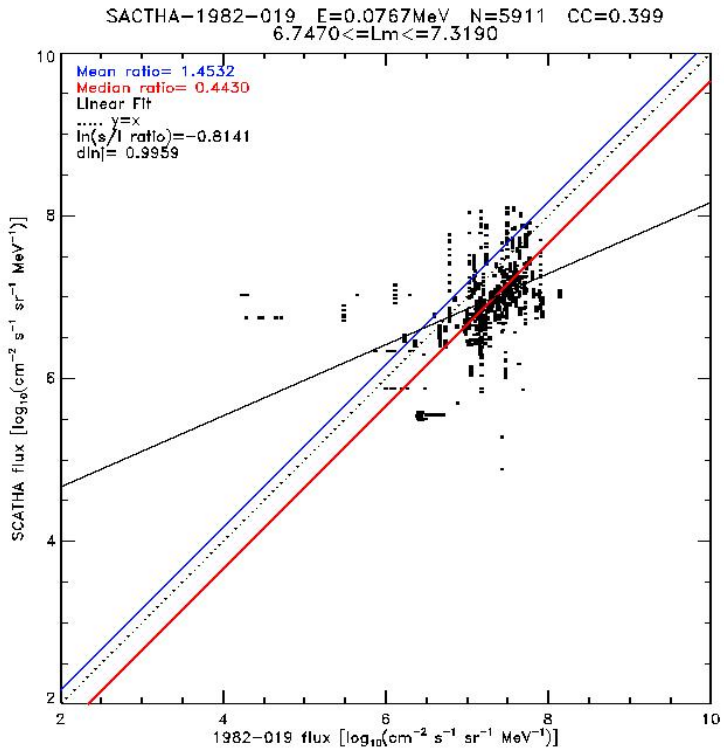


Figure A23: Cross-calibration results, SCATHA vs. 1982-019, E=76.7 keV

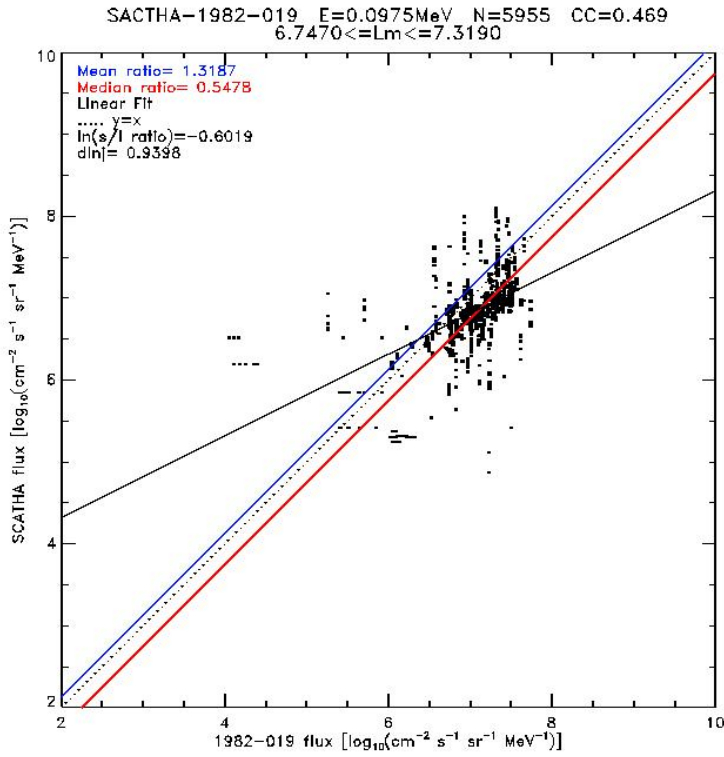


Figure A24: Cross-calibration results, SCATHA vs. 1982-019, E=97.5 keV

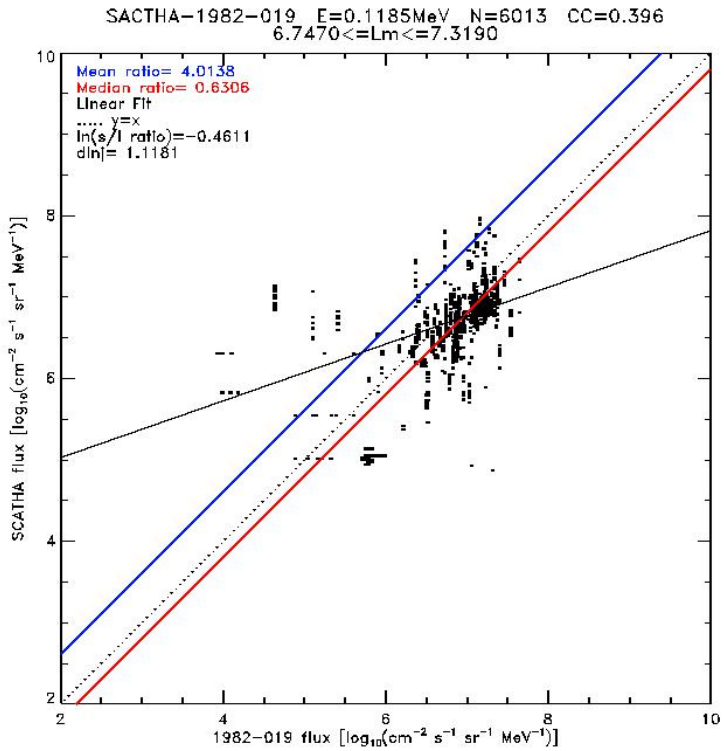


Figure A25: Cross-calibration results, SCATHA vs. 1982-019, E=118.5 keV

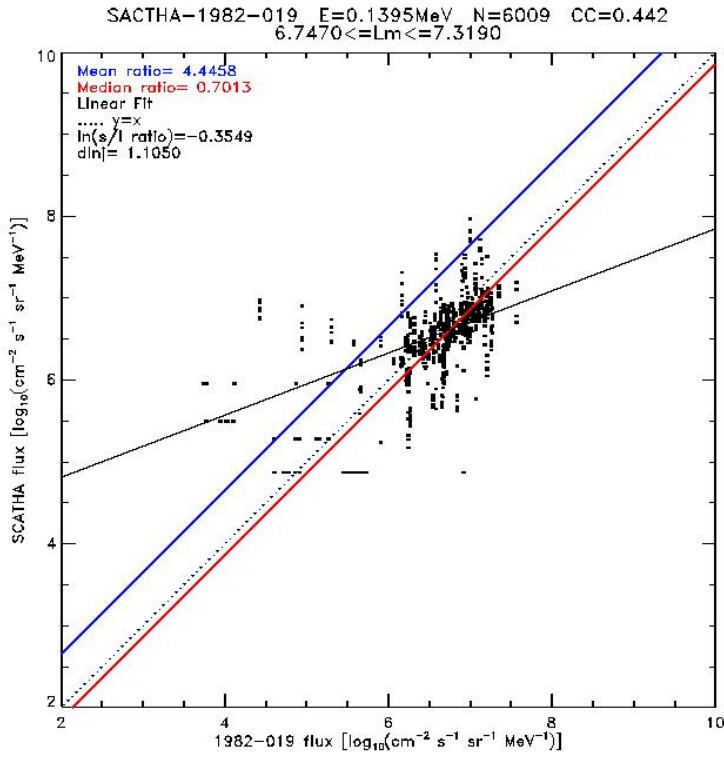


Figure A26: Cross-calibration results, SCATHA vs. 1982-019, E=139.5 keV

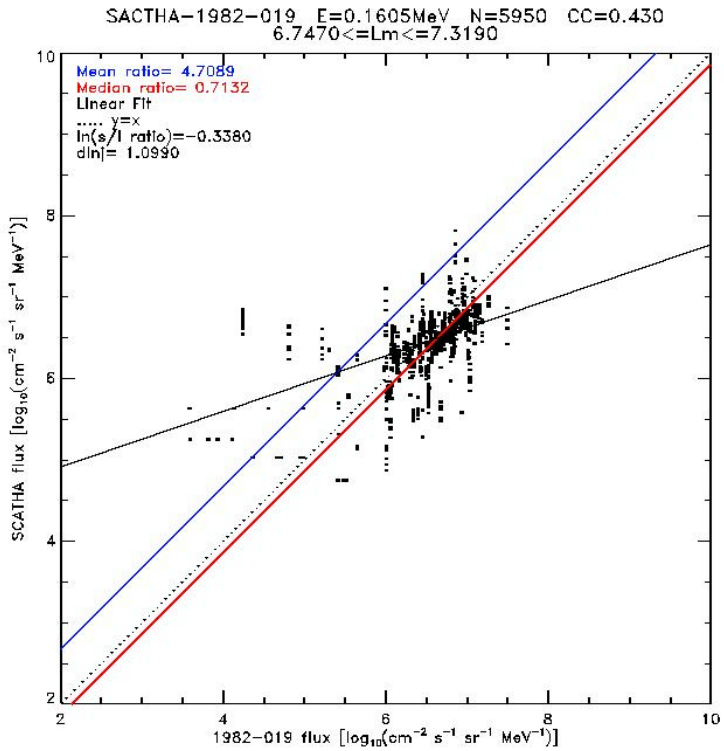


Figure A27: Cross-calibration results, SCATHA vs. 1982-019, E=160.5 keV

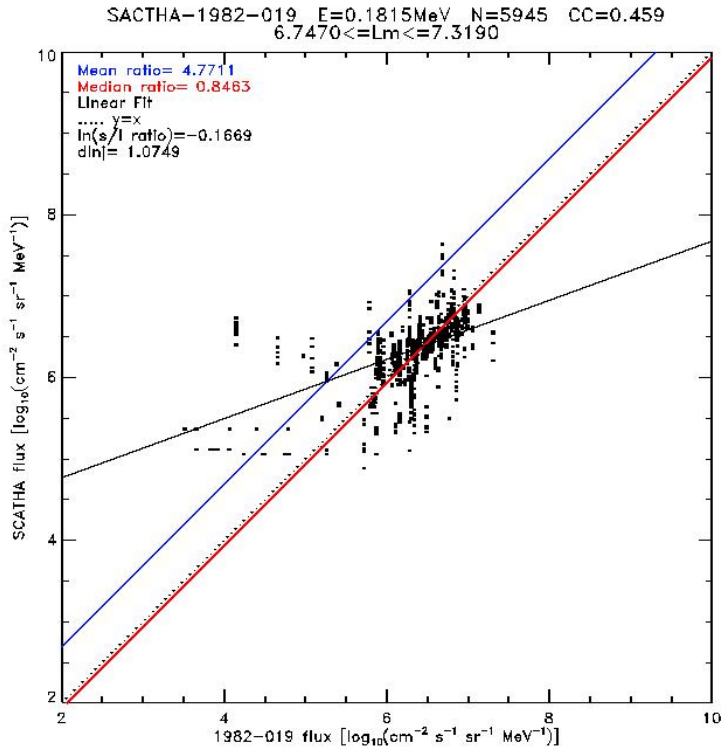


Figure A28: Cross-calibration results, SCATHA vs. 1982-019, E=181.5 keV

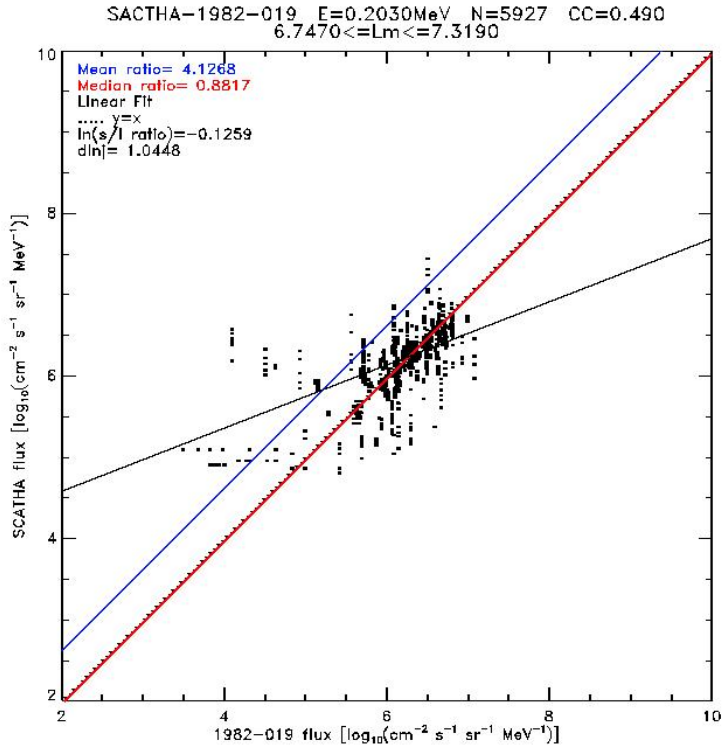


Figure A29: Cross-calibration results, SCATHA vs. 1982-019, E=203 keV

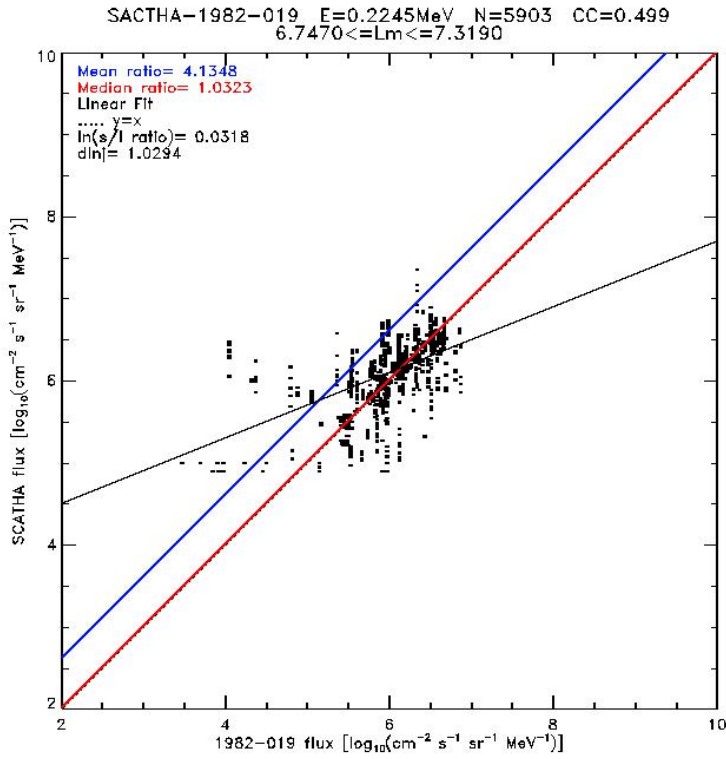


Figure A30: Cross-calibration results, SCATHA vs. 1982-019, E=224.5 keV

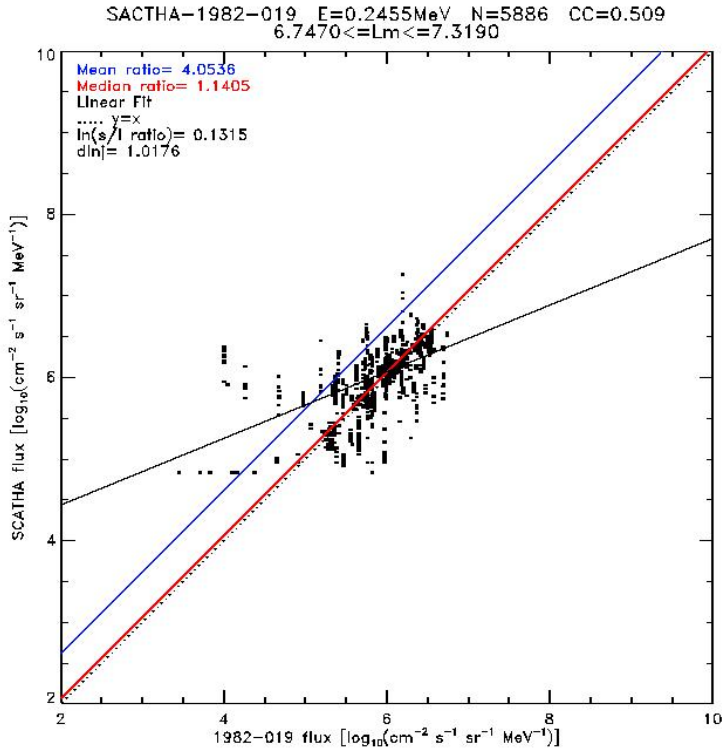


Figure A31: Cross-calibration results, SCATHA vs. 1982-019, E=245.5 keV

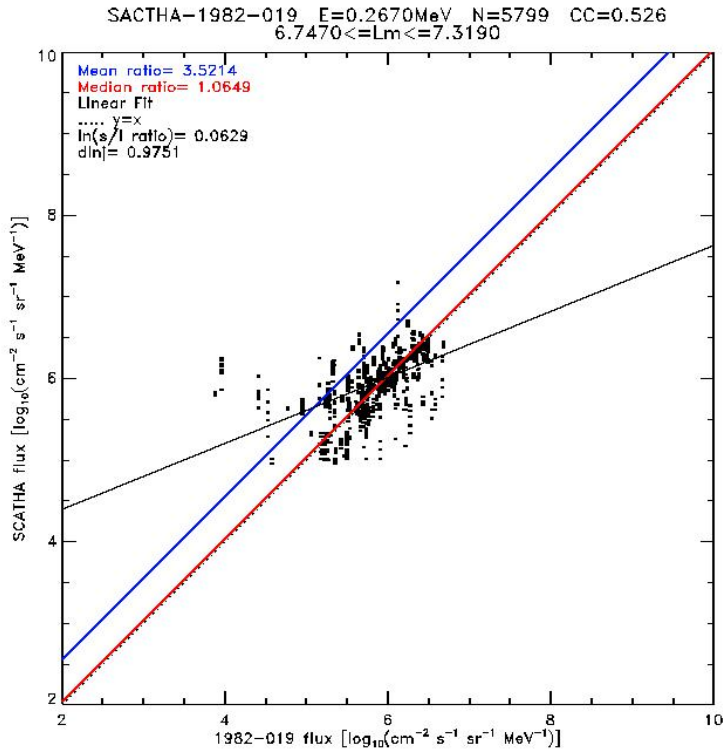


Figure A32: Cross-calibration results, SCATHA vs. 1982-019, E=267 keV

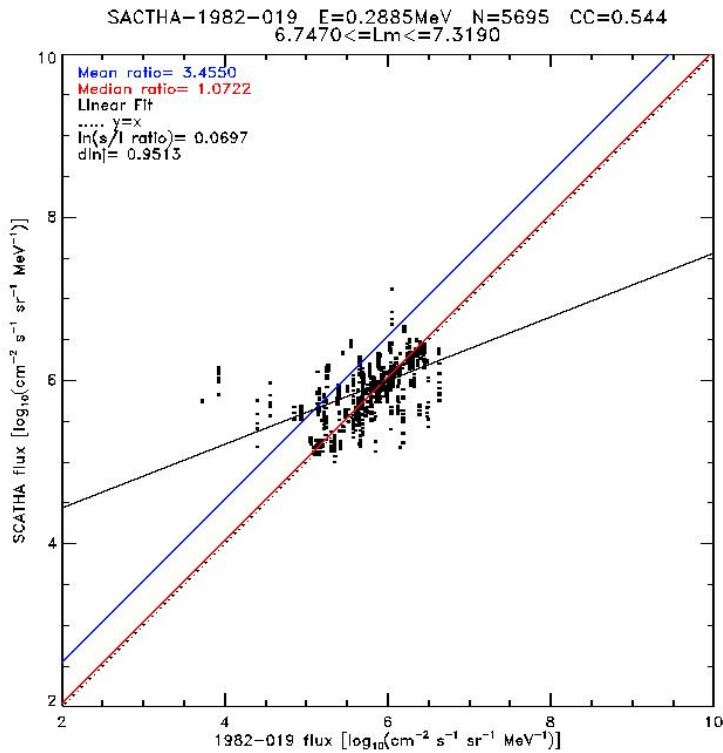


Figure A33: Cross-calibration results, SCATHA vs. 1982-019, E=288.5 keV

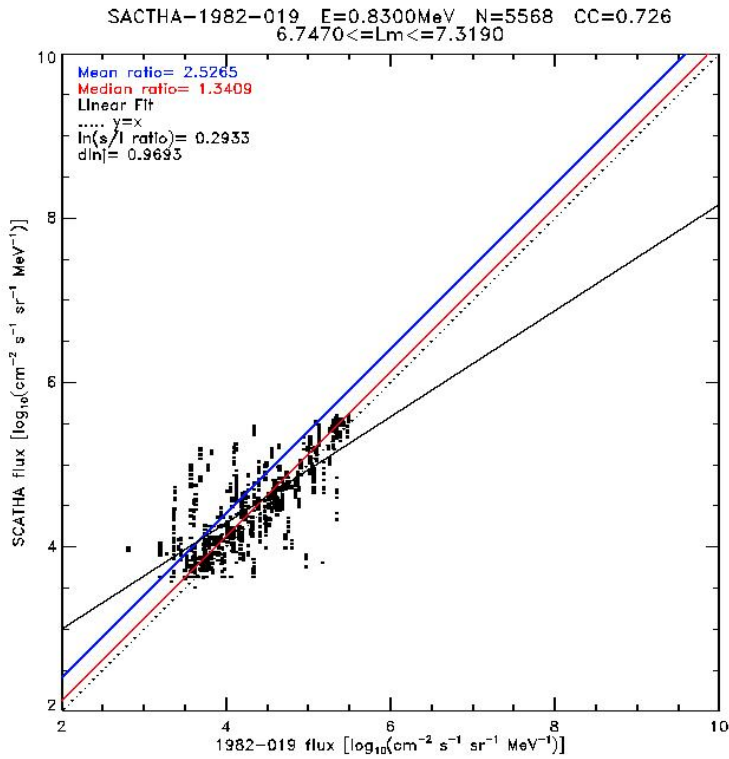


Figure A34: Cross-calibration results, SCATHA vs. 1982-019, E=830 keV

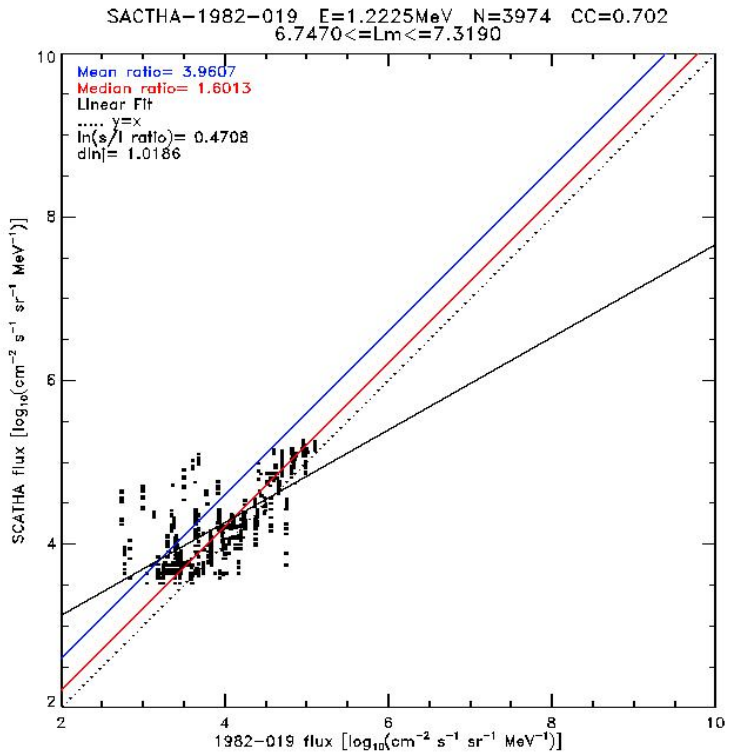


Figure A35: Cross-calibration results, SCATHA vs. 1982-019, E=1222.5 keV

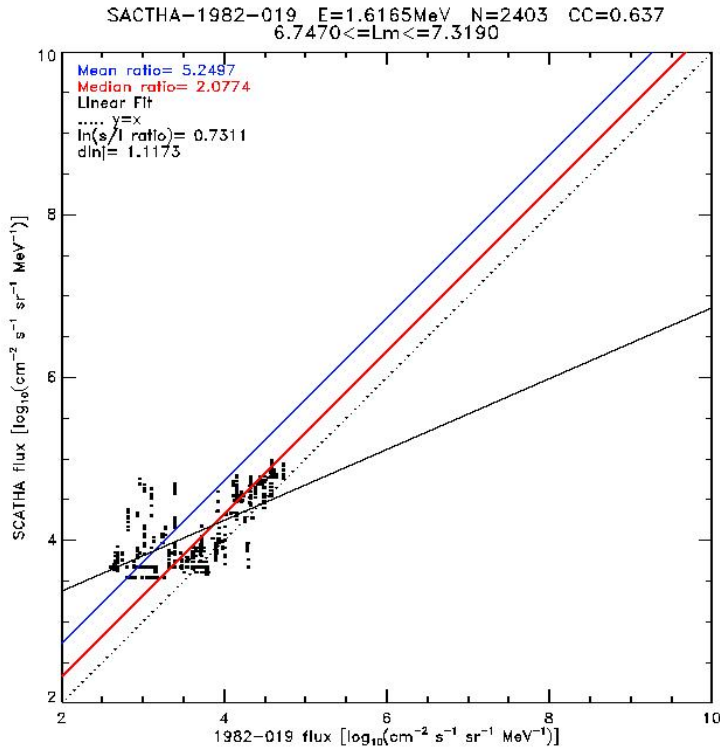


Figure A36: Cross-calibration results, SCATHA vs. 1982-019, E=1616.5 keV

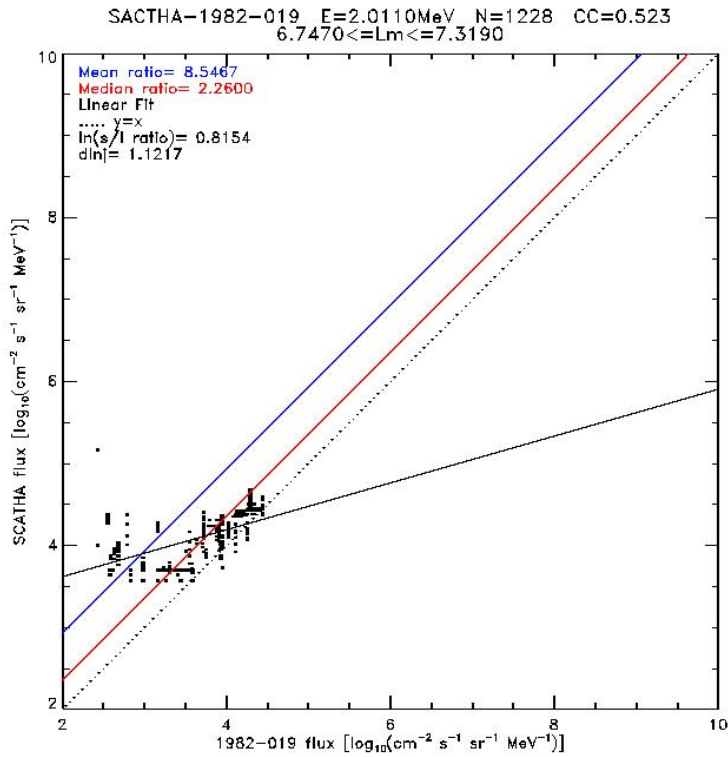


Figure A37: Cross-calibration results, SCATHA vs. 1982-019, E=2011 keV

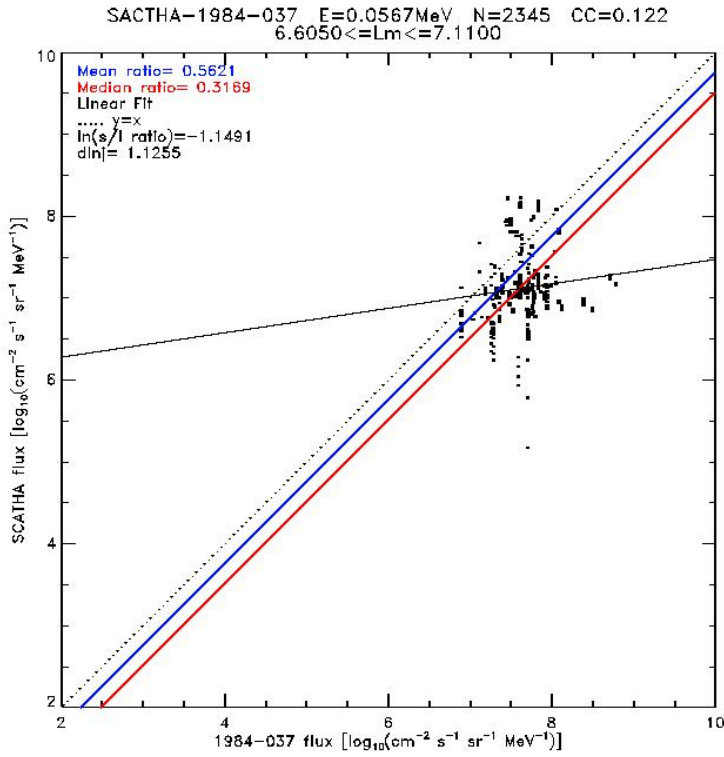


Figure A38: Cross-calibration results, SCATHA vs. 1984-037, E=56.7 keV

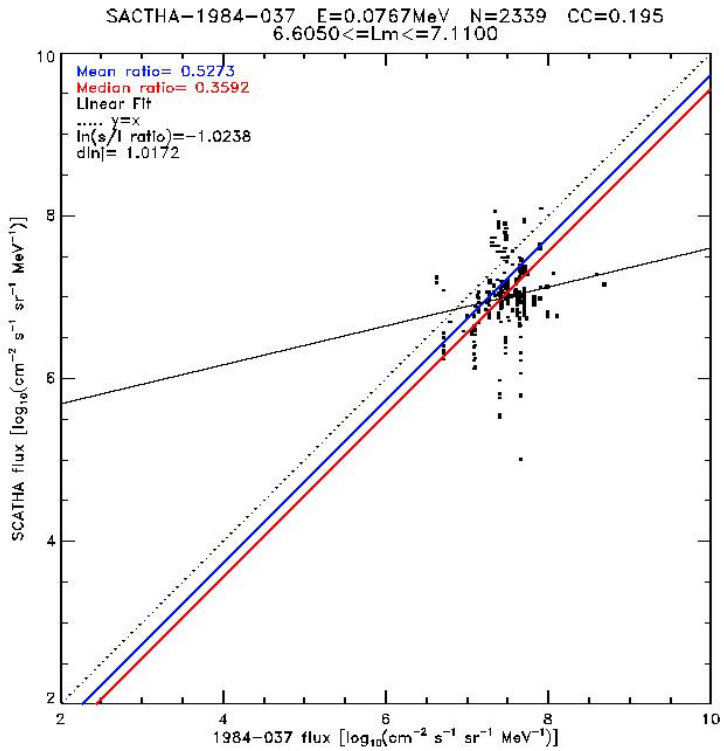


Figure A39: Cross-calibration results, SCATHA vs. 1984-037, E=76.7 keV

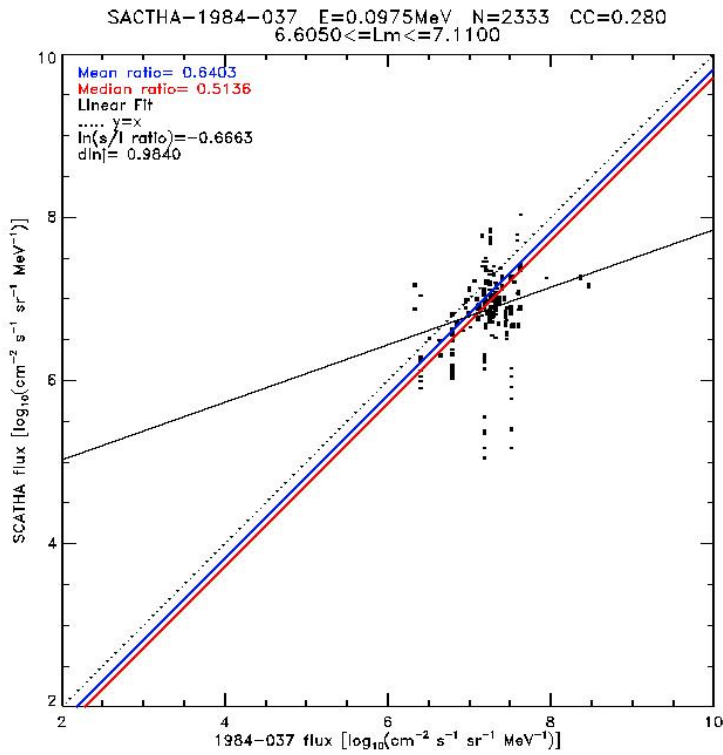


Figure A40: Cross-calibration results, SCATHA vs. 1984-037, E=97.5 keV

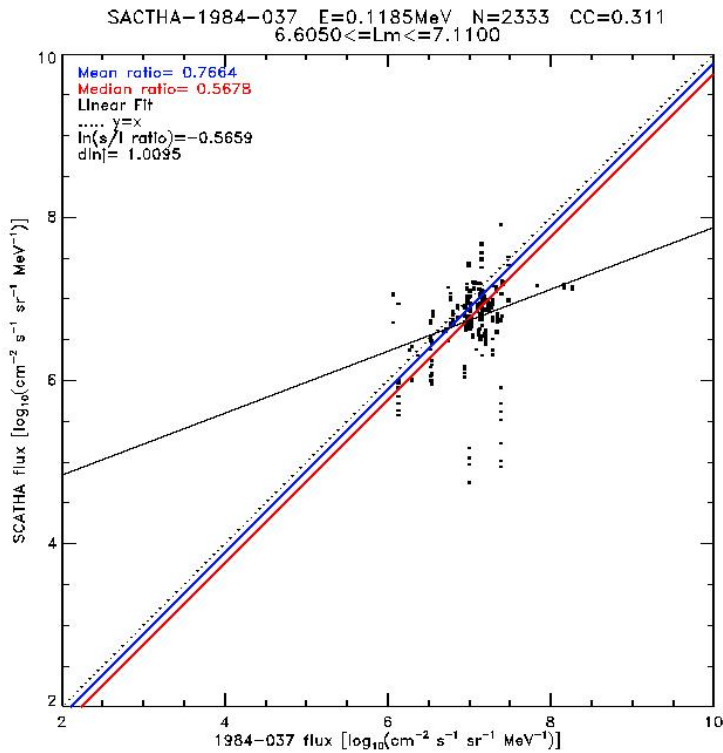


Figure A41: Cross-calibration results, SCATHA vs. 1984-037, E=118.5 keV

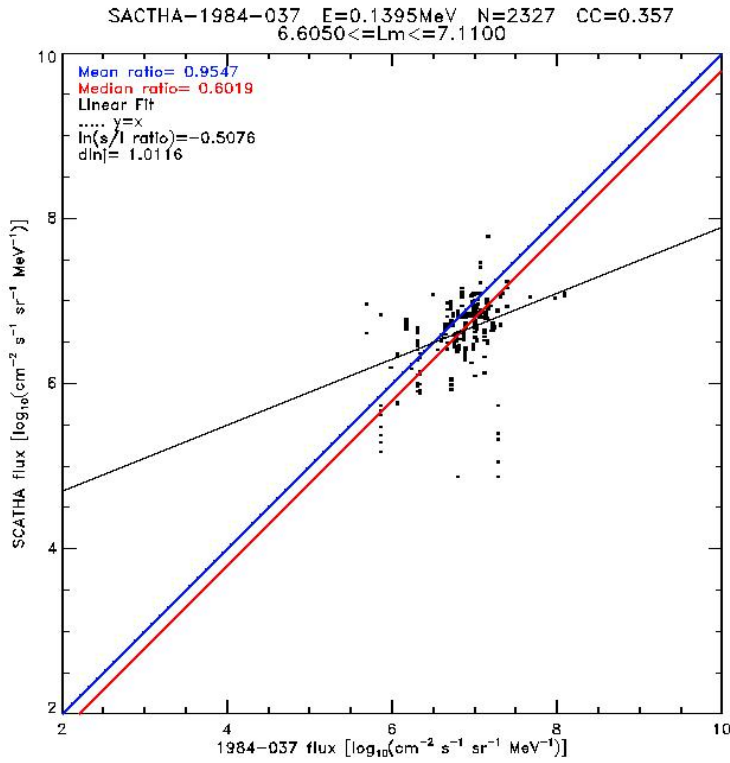


Figure A42: Cross-calibration results, SCATHA vs. 1984-037, E=139.5 keV

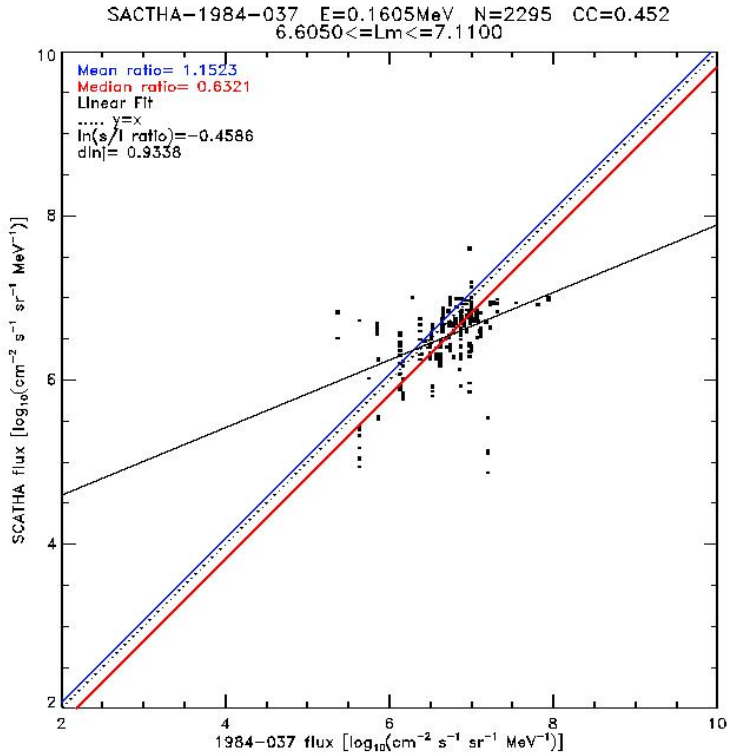


Figure A43: Cross-calibration results, SCATHA vs. 1984-037, E=160.5 keV

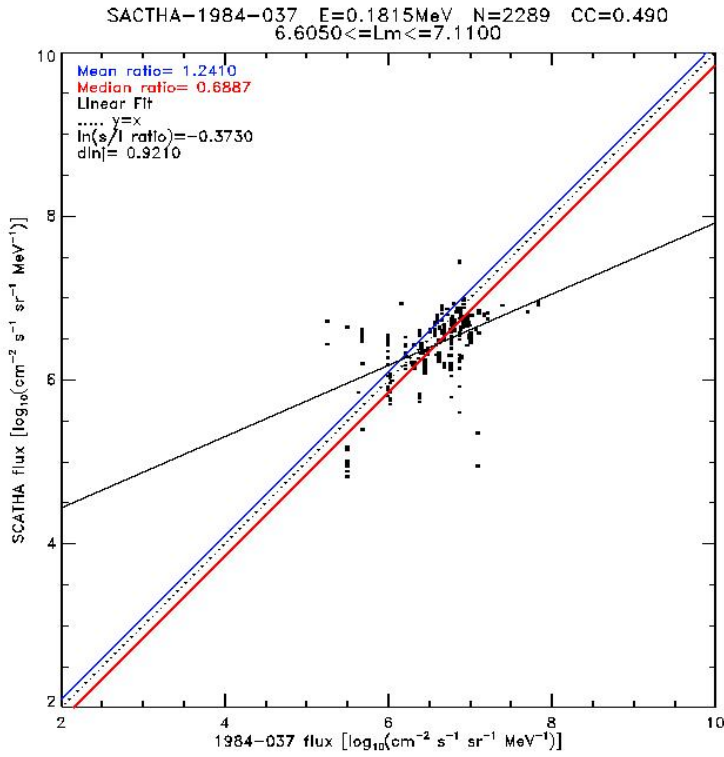


Figure A44: Cross-calibration results, SCATHA vs. 1984-037, E=181.5 keV

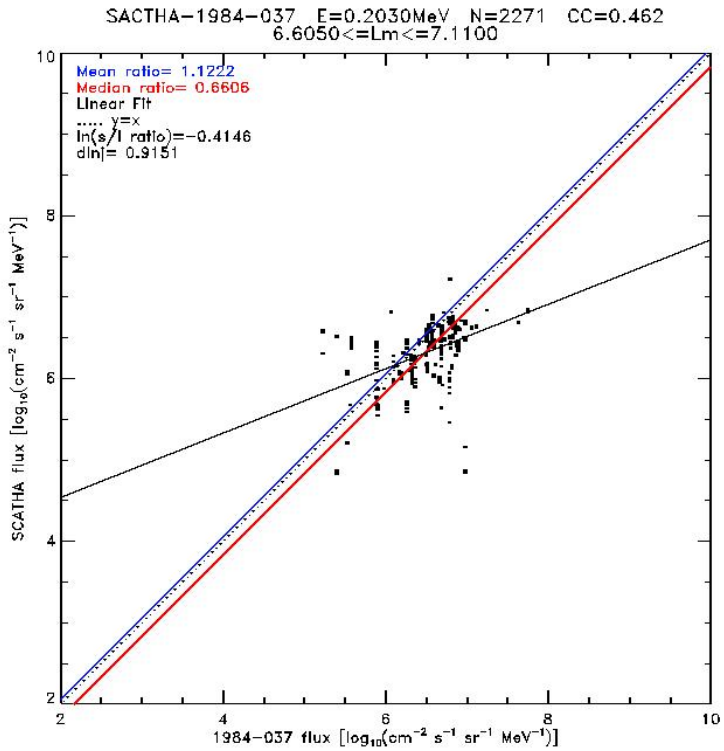


Figure A45: Cross-calibration results, SCATHA vs. 1984-037, E=203 keV

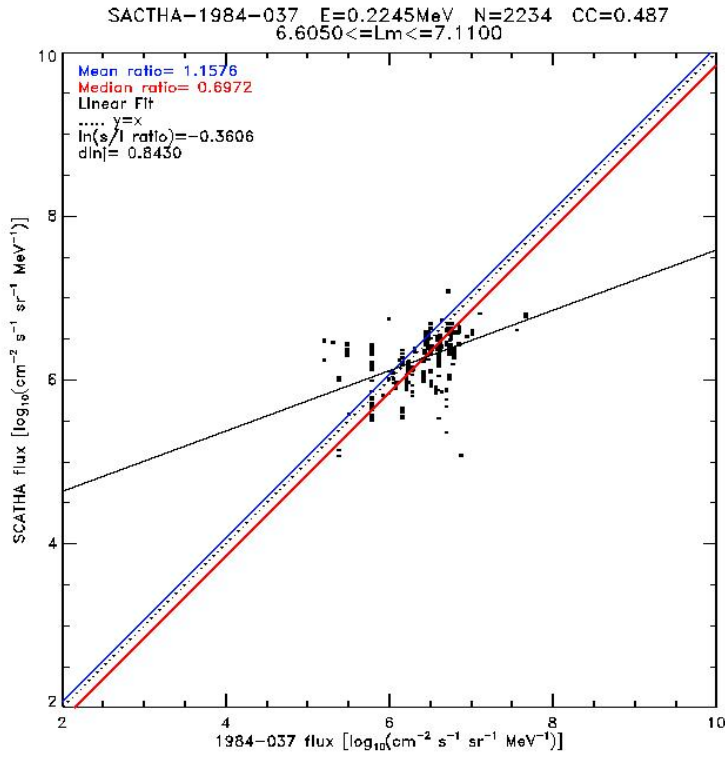


Figure A46: Cross-calibration results, SCATHA vs. 1984-037, E=224.5 keV

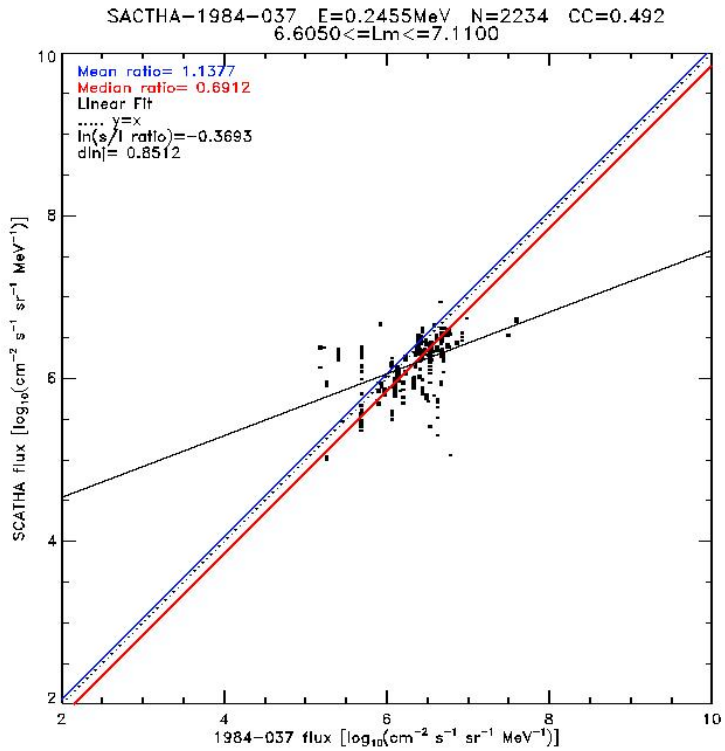


Figure A47: Cross-calibration results, SCATHA vs. 1984-037, E=245.5 keV

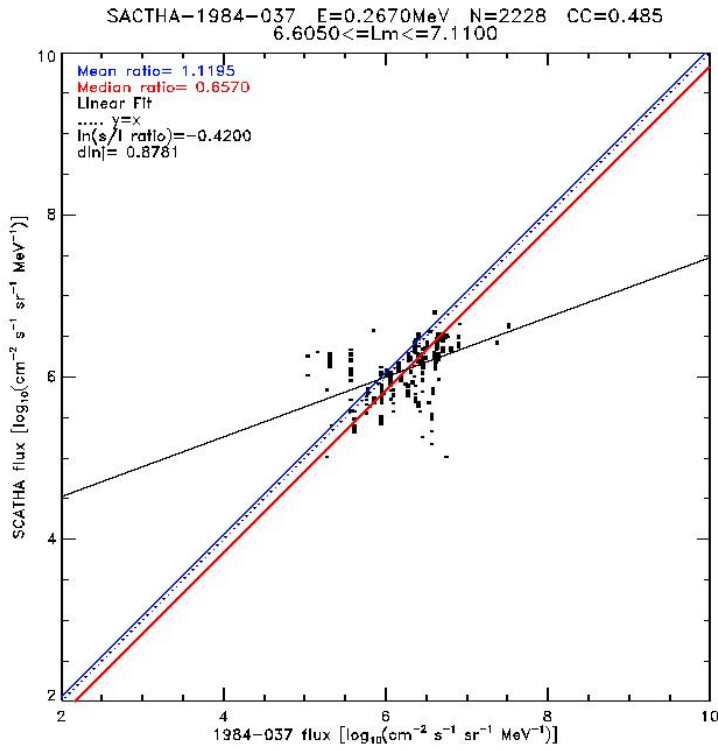


Figure A48: Cross-calibration results, SCATHA vs. 1984-037, E=267 keV

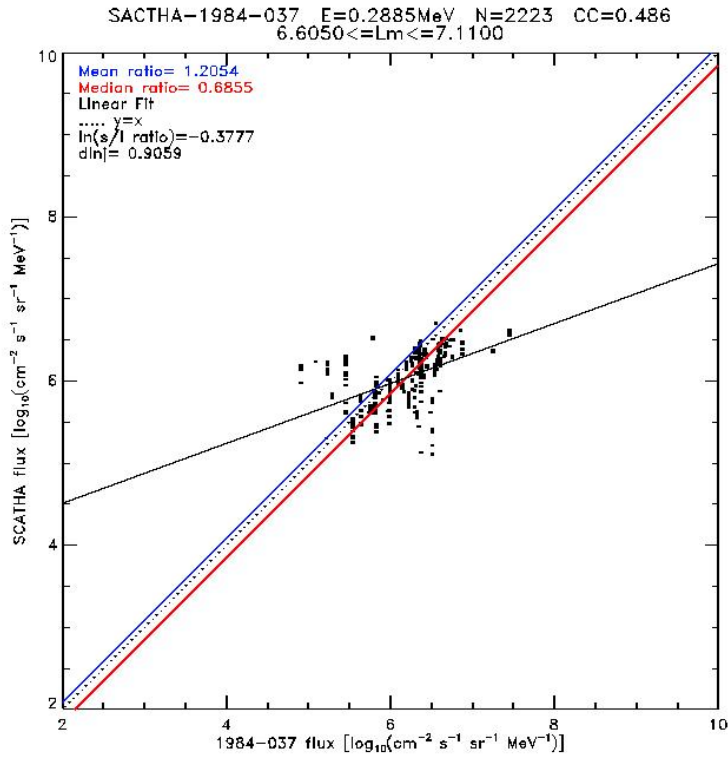


Figure A49: Cross-calibration results, SCATHA vs. 1984-037, E=288.5 keV

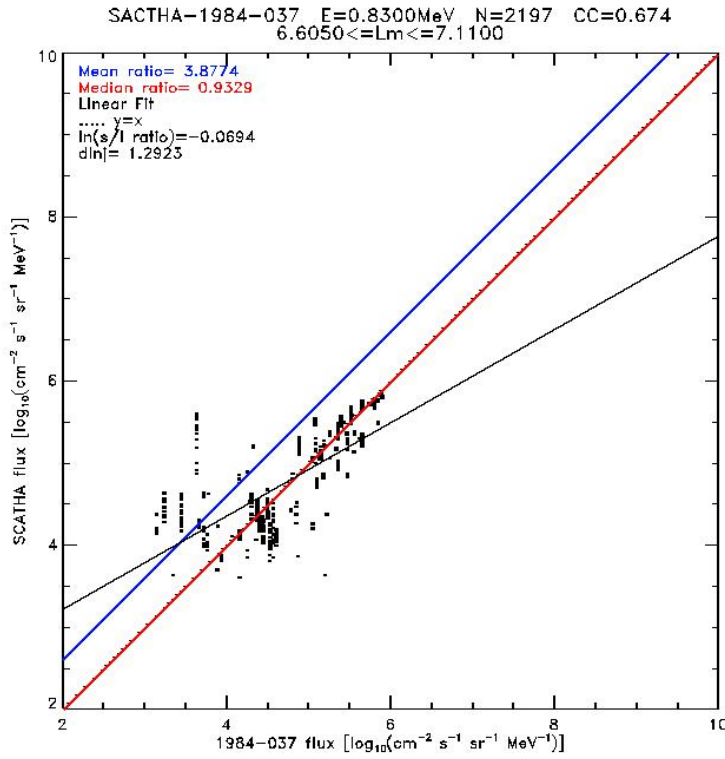


Figure A50: Cross-calibration results, SCATHA vs. 1984-037, E=830 keV

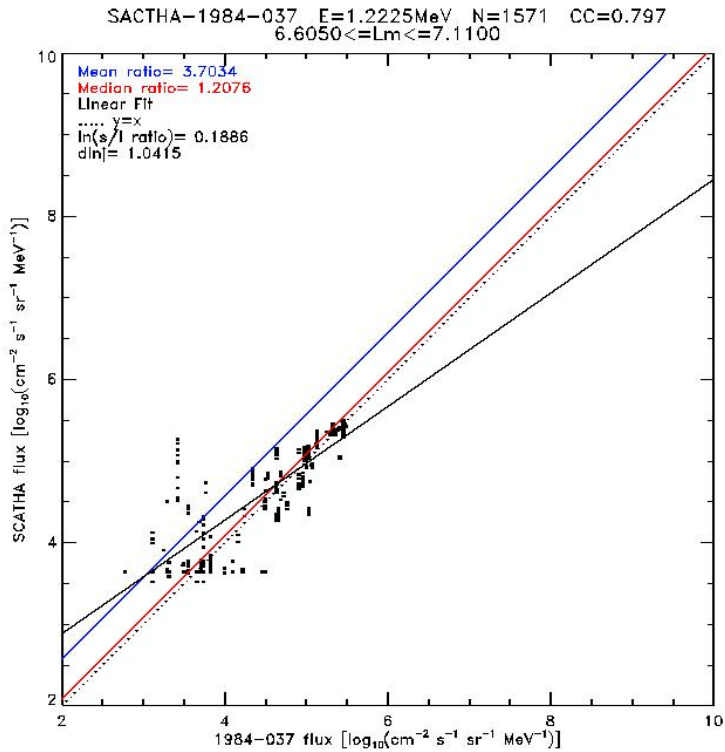


Figure A51: Cross-calibration results, SCATHA vs. 1984-037, E=1222.5keV

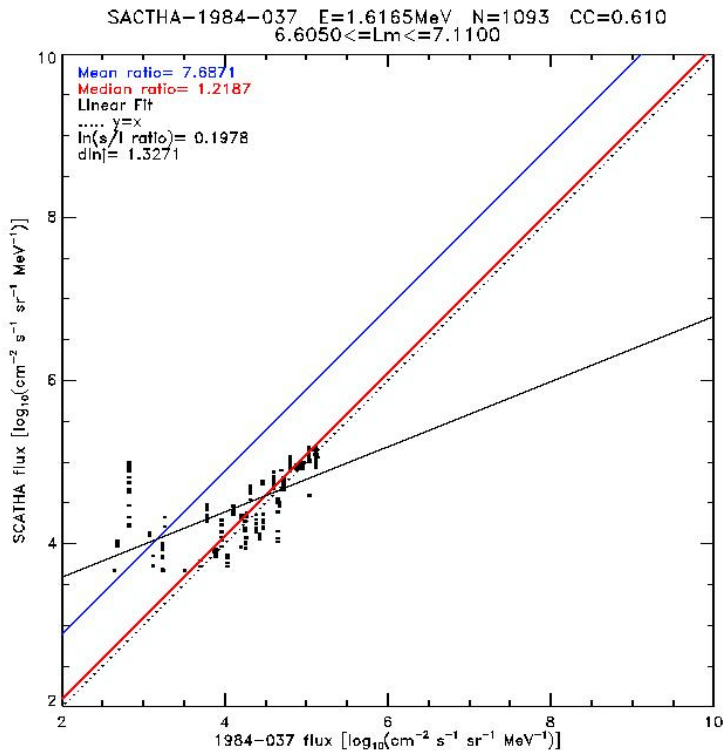


Figure A52: Cross-calibration results, SCATHA vs. 1984-037, E=1616.5 keV

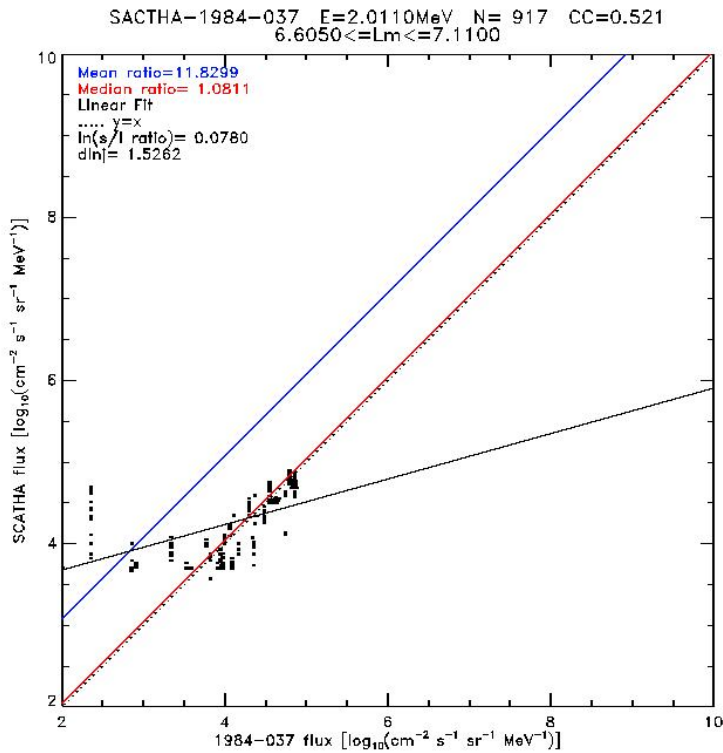


Figure A53: Cross-calibration results, SCATHA vs. 1984-037, E=2011 keV

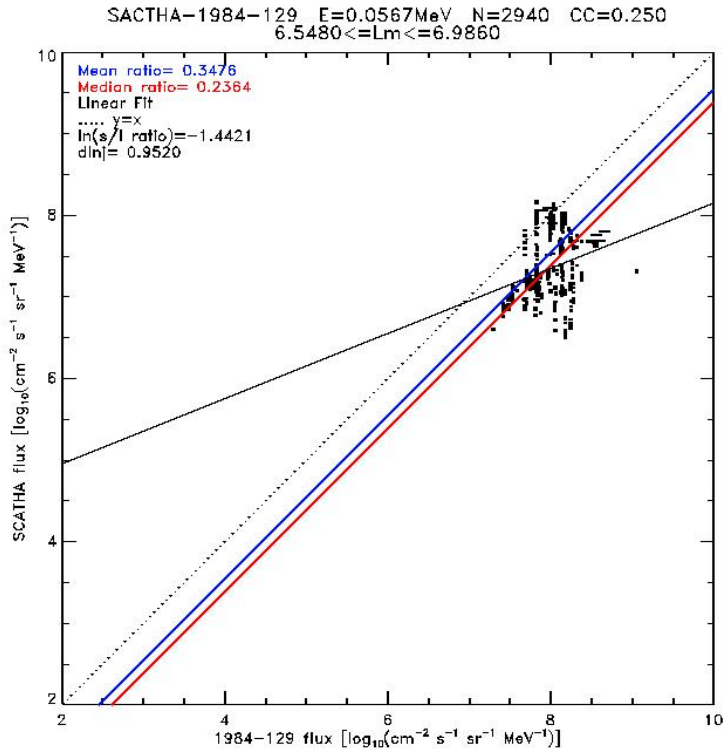


Figure A54: Cross-calibration results, SCATHA vs. 1984-129, E=56.7 keV

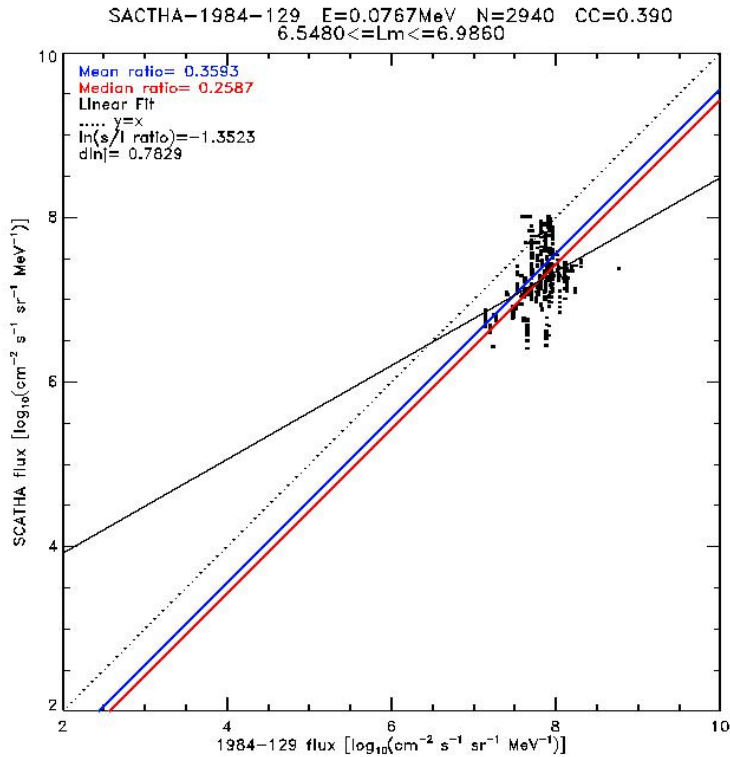


Figure A55: Cross-calibration results, SCATHA vs. 1984-129, E=76.7 keV

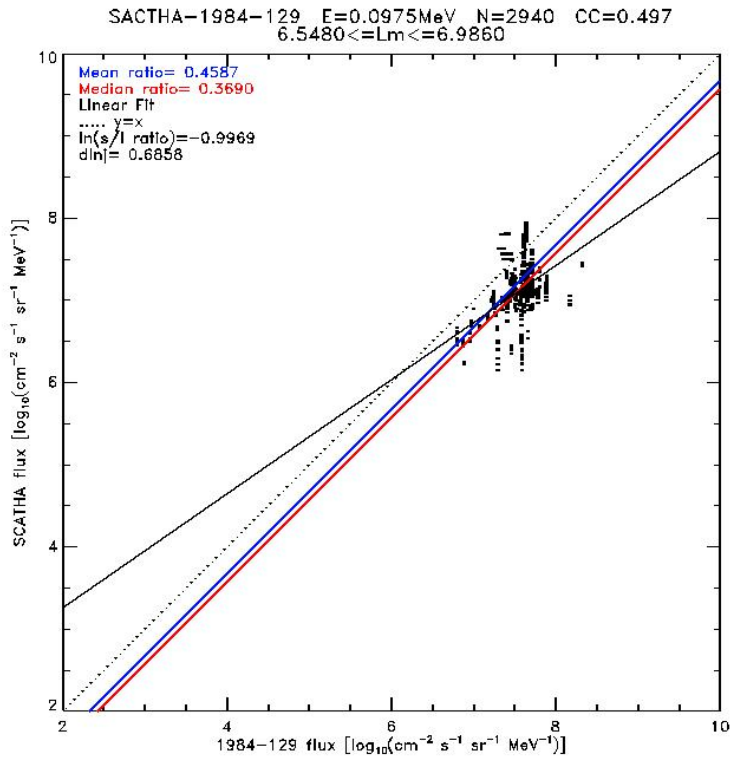


Figure A56: Cross-calibration results, SCATHA vs. 1984-129, E=97.5 keV

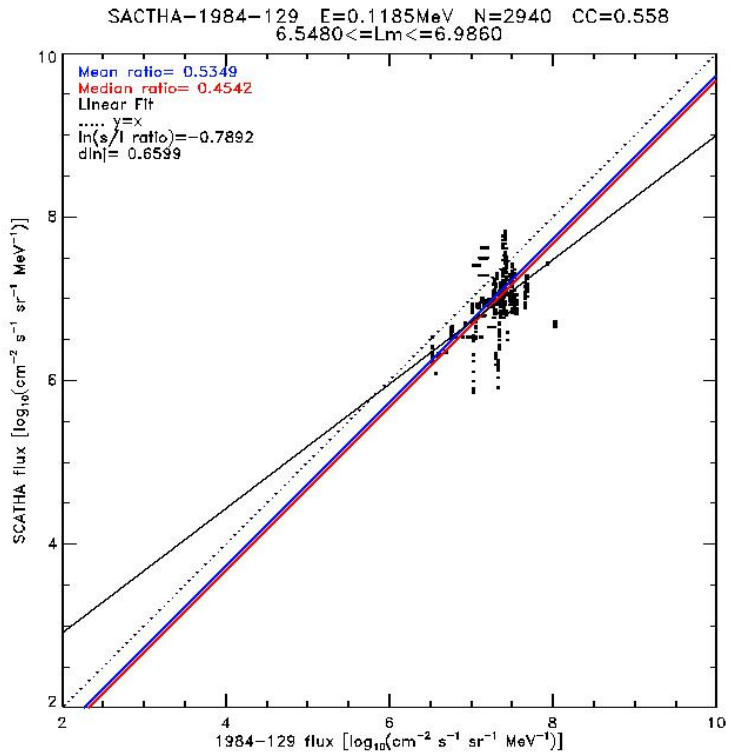


Figure A57: Cross-calibration results, SCATHA vs. 1984-129, E=118.5 keV

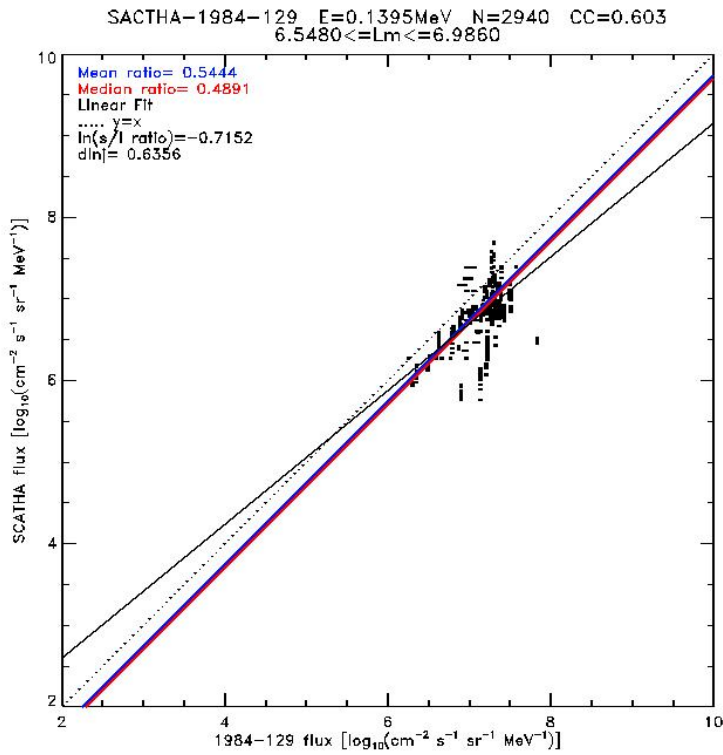


Figure A58: Cross-calibration results, SCATHA vs. 1984-129, E=139.5 keV

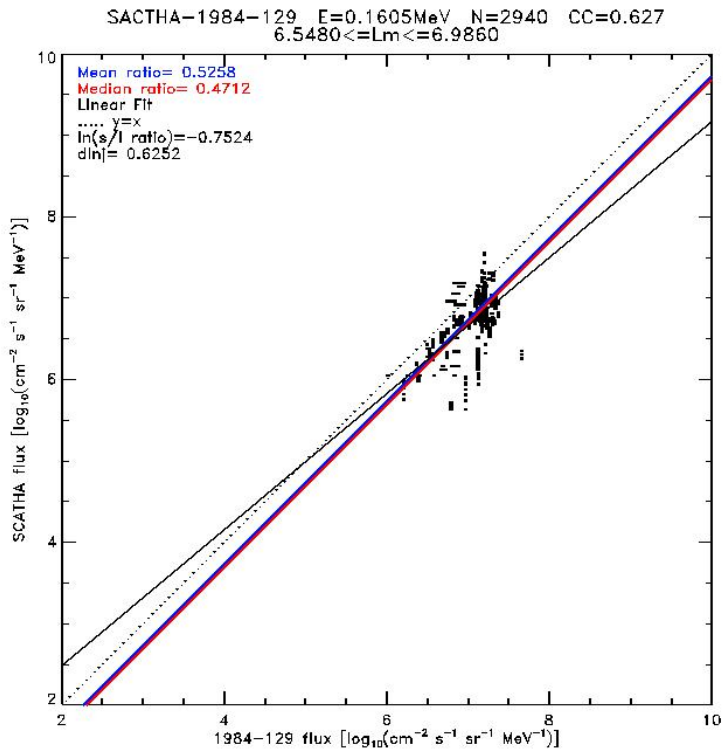


Figure A59: Cross-calibration results, SCATHA vs. 1984-129, E=160.5 keV

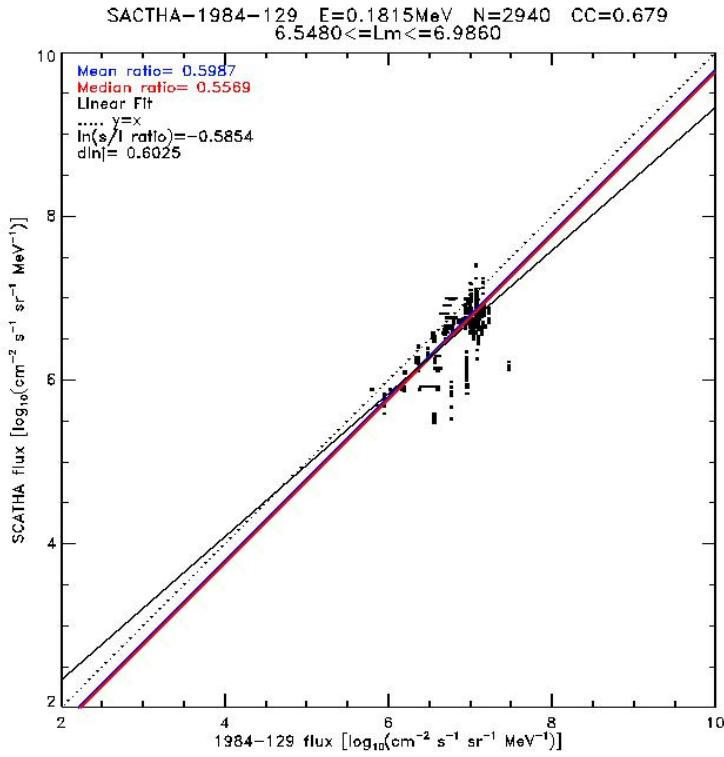


Figure A60: Cross-calibration results, SCATHA vs. 1984-129, E=181.5 keV

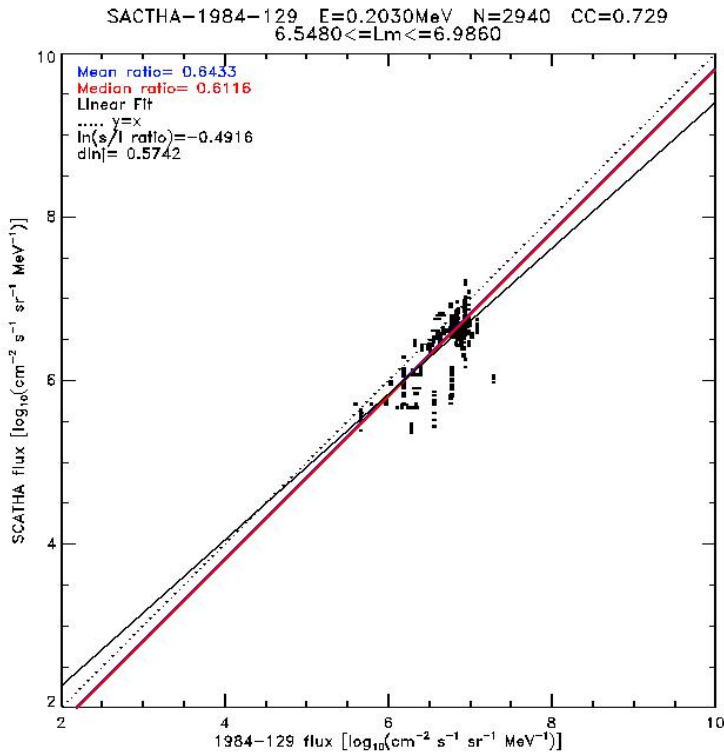


Figure A61: Cross-calibration results, SCATHA vs. 1984-129, E=203 keV

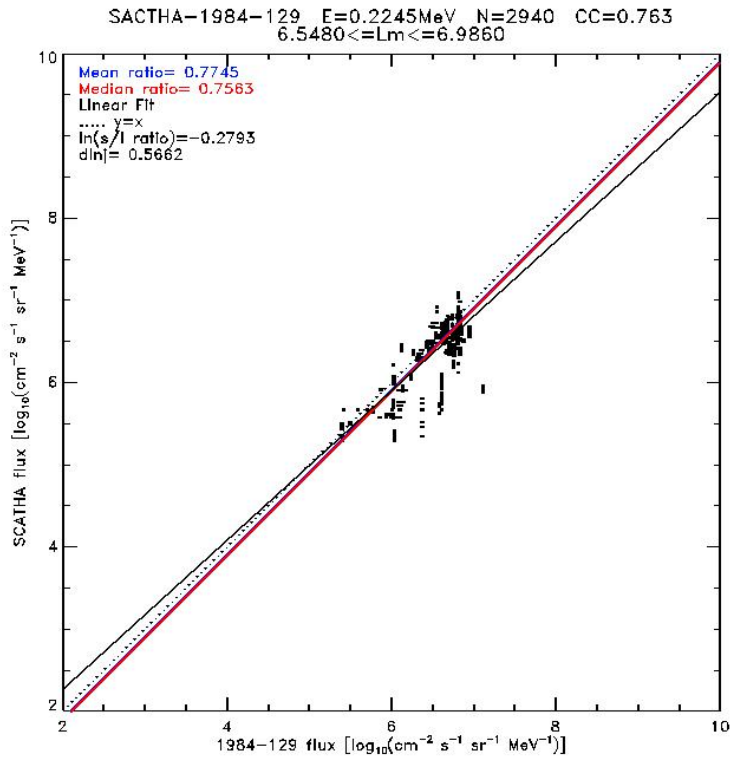


Figure A62: Cross-calibration results, SCATHA vs. 1984-129, E=224.5 keV

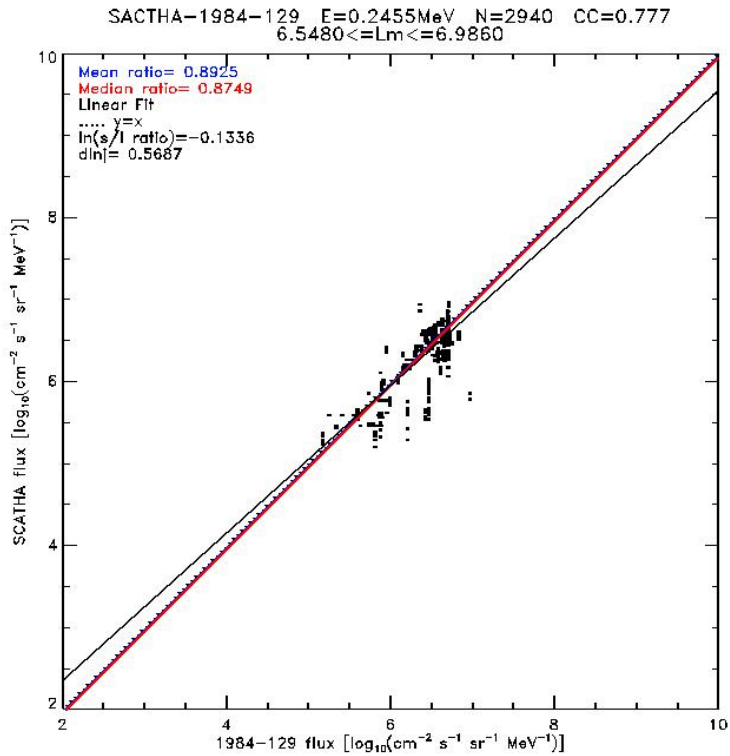


Figure A63: Cross-calibration results, SCATHA vs. 1984-129, E=245.5 keV

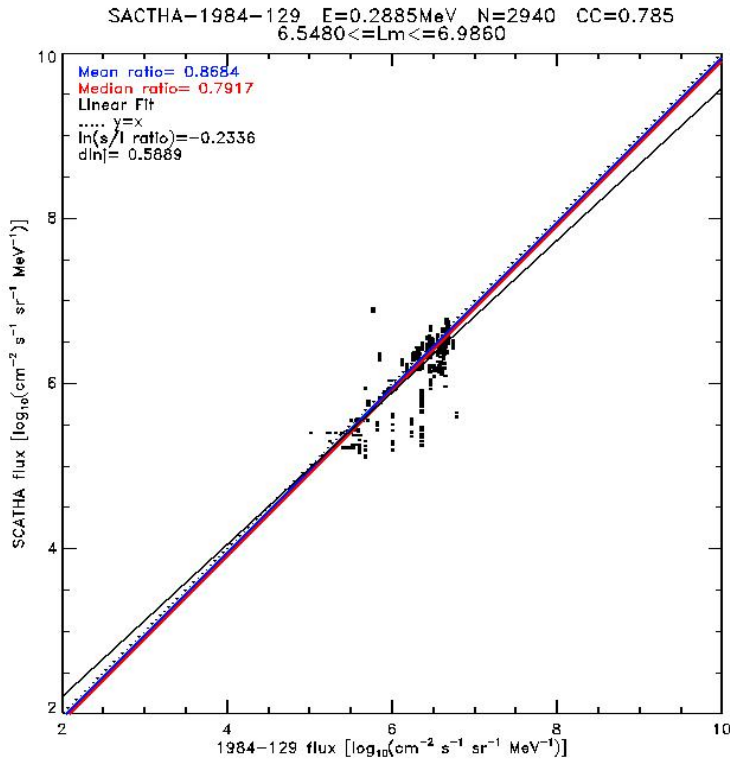


Figure A64: Cross-calibration results, SCATHA vs. 1984-129, E=288.5 keV

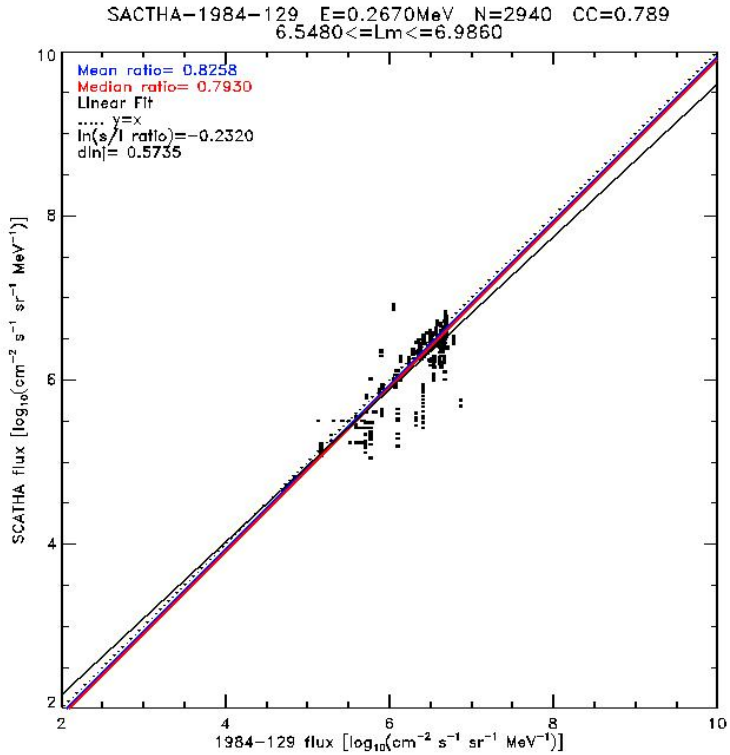


Figure A65: Cross-calibration results, SCATHA vs. 1984-129, E=267 keV

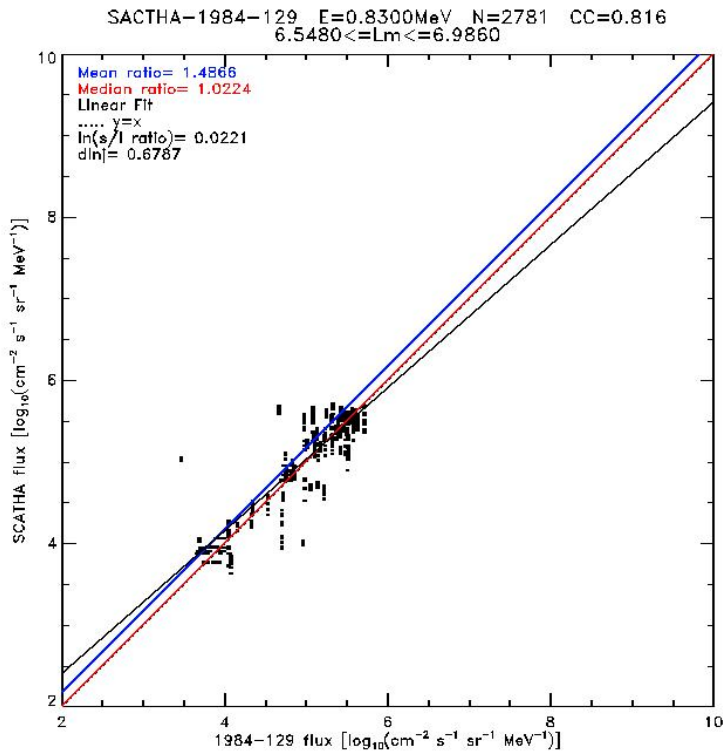


Figure A66: Cross-calibration results, SCATHA vs. 1984-129, E=830 keV

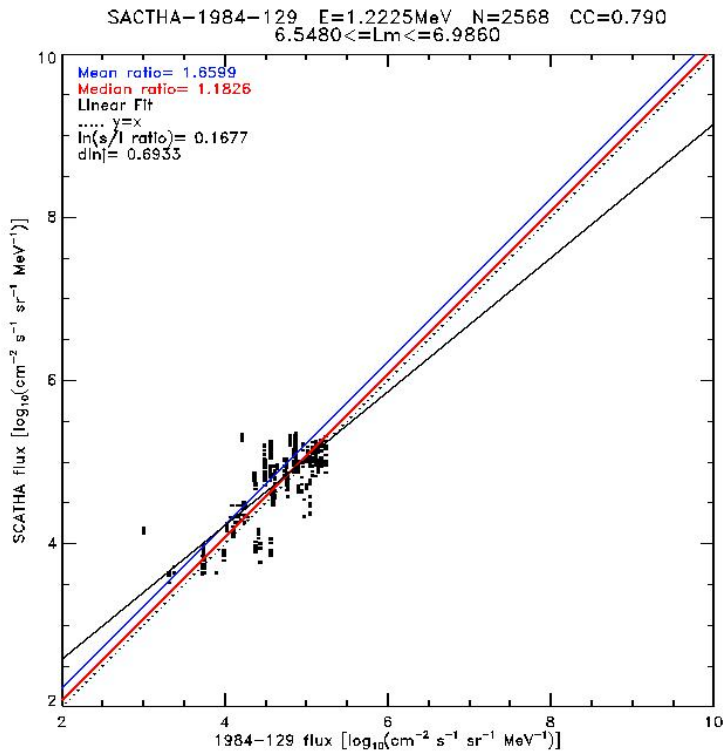


Figure A67: Cross-calibration results, SCATHA vs. 1984-129, E=1222.5 keV

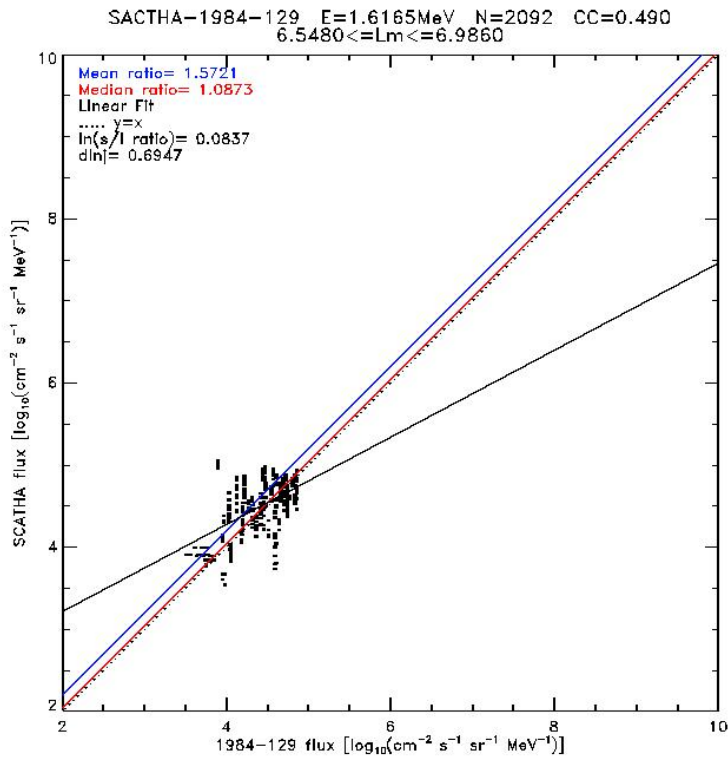


Figure A68: Cross-calibration results, SCATHA vs. 1984-129, E=1616.5 keV

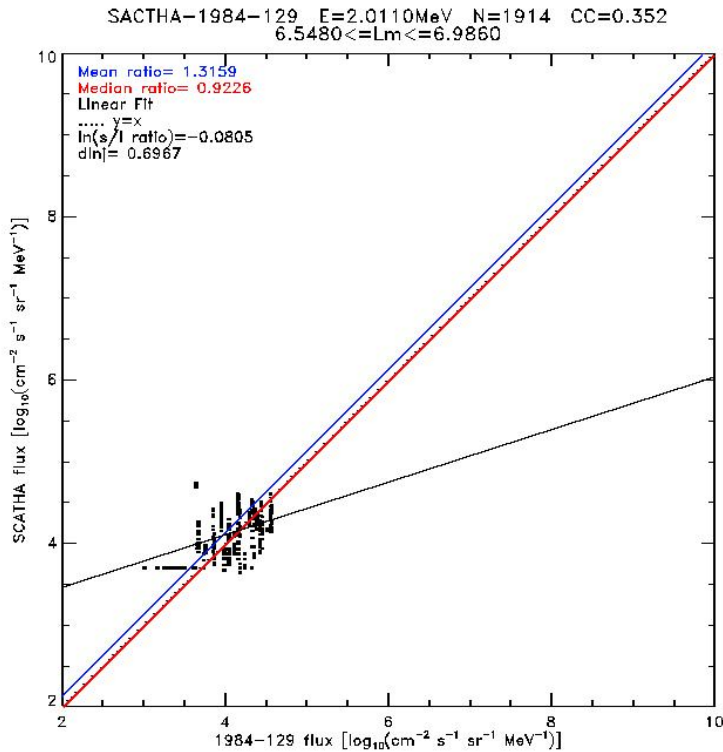


Figure A69: Cross-calibration results, SCATHA vs. 1984-129, E=2011 keV

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